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Nonlinearity, state-dependency and asymmetry of the monetary transmission mechanism – some evidence from the Greenspan era

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Summary

The thesis deals with the problems of nonlinearity and state-dependency of the monetary transmission model and asymmetric impulse responses in the Greenspan era. The main aim of the thesis is to verify whether the standard assumption of linearity and state-independency of the monetary transmission model holds in practice when a small three-equation model of monetary transmission is confronted with a broad set of data. The issue of asymmetric monetary transmission is of utmost importance from the perspective of strategic dilemmas regarding optimal scheduling of monetary policy actions. The literature overview leaves very little doubt that there are many theoretical and empirical reasons to believe that monetary transmission exhibits significant sign, size and state asymmetries no matter whether we make some general considerations or whether we focus solely on the Greenspan era. The econometric analysis performed here, based on the $STAR$ framework, delivers statistically significant sign and size asymmetries, but the obtained patterns are not robust among the estimated models. On the other hand, the adopted framework is successful at identifying sources of state-dependency of the estimated equations and state asymmetry of monetary transmission. Variables from all but one of the defined groups are found to deliver significant patterns of state asymmetry and, at the same time, the obtained patterns of state asymmetries are explicable from the theoretical point of view. We find the results to be useful from the perspective of conducting the monetary policy in practice.

Key words

nonlinearity, state-dependency, asymmetry, monetary transmission, Greenspan era, $STAR$

Area of study (codes according to Erasmus Subject Area Codes List)

14.3 Economics

The title of the thesis in Polish

Nieliniowość, asymetria i zależność od warunków początkowych mechanizmu transmisji monetarnej ery Alana Greenspana

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Introduction

Any economic or econometric model is a great simplification of a complex economic reality and necessarily requires some simplifying (sometimes *ad hoc* and *implicit*) assumptions. The question to be asked is not whether the model omits some aspects of the reality but rather whether it emphasises everything that is crucial and important from the perspective of the problem being investigated and puts aside all the disturbing noise in order to see the crux of the matter. This issue is of utmost importance when models are something more than just purely theoretical exercises and when they serve as some kind of justification or rationale behind economic policies which may influence wealth or its distribution in society.

This is also the case for monetary policy and its modelling. It seems that there is a wide consensus regarding the advantages of reasonably low and stable inflation and neutrality or near-neutrality of money in the long run. At the same time, however, there is still an ongoing debate as to how exactly the monetary transmission mechanism operates over the short- and medium-term horizon and what its exact channels and their relative importance are. In some respects the situation may even be worse than we thought it was before Bernanke and Gertler (1995) wrote that the monetary transmission mechanism was like a black box – we knew the ins (impulses) and outs (effects) but we did not know what was inside (the channels of the monetary policy and their importance). The recent crisis again brought some doubts about whether we are fully aware of the effects of the monetary policy, to say nothing of whether we have an in-depth understanding of various channels of the monetary transmission mechanism and their interactions.

Probably the most self-evident shortcomings of monetary transmission models prior to the crisis era come from neglecting the financial sector and issues related to financial and macroeconomic stability. In particular, some economists (e.g. Taylor 2009) argue that the monetary policy may play an important role in co-creating boom-bust cycles in which losses from the bust period may surpass gains from the boom period. At the same time, a quite popular if not predominant, at least until the recent crisis, position on this issue which was taken by central bankers held that the monetary policy should wait and mop up after bubble bursts by cutting interest rates rather than preventively hiking rates in order to prick or deflate the bubble. Nevertheless, nonstandard measures adopted by many central banks after the Lehman Brothers collapse show that e.g. a *zero lower bound* on nominal interest rates should be taken into consideration.

The above-mentioned concerns shed some light on just a few of the nontrivial effects and conditions of the monetary policy as revealed by the recent crisis. In this paper we move backwards even further and ask whether the black box of the monetary transmission mechanism hides more peculiarities which are not covered in regular textbooks on the monetary policy but, in contrast to many recent papers, we do not want to focus on issues directly and exclusively regarding the recent crisis and financial or macroeconomic stability. Specifically, we are interested in nonlinearity and state-dependency of the monetary transmission mechanism resulting in asymmetric impulse responses on a more frequent basis than once or twice in a century.

In other words, we question one of the most popular but very often implicit assumptions of the linearity of equations describing the monetary transmission mechanism and constancy of the estimated parameters. We acknowledge that these assumptions may fail when it comes to extremely turbulent periods, such as the pre-World War II recessions (in particular the Great Depression) or the recent Great Recession, but we want to verify whether the linearity and constancy assumptions hold true in quieter times and during milder crises or recessions, such as those preceding the recent one. Moreover, we are interested whether asymmetric impulse responses are only an occasional exception or, perhaps, the rule?

In section 2 we survey the existing literature on general concepts and rationales standing behind potential nonlinearity and state-dependency of the monetary transmission mechanism. We show that there are quite many theoretical reasons for a nonlinear and state-dependent reaction of the economy to interest rates and *vice versa* – a nonlinear and state-dependent reaction of interest rates to changes in the economy. Empirical studies confirm, by and large, such predictions, however, it is usually difficult to pinpoint and separate the exact theoretical sources of the observed nonlinearities and state-dependencies due to the many interactions and interrelations among them. Similarly, there are some papers evidencing asymmetric impulse responses of the economy to monetary policy shocks.

In this paper we address the question of nonlinearity and state-dependency of the monetary transmission mechanism and asymmetric impulse responses by analysing the Greenspan era. Naturally, choosing the U.S economy and this period may seem subjective (and to some extent it surely is) but we have quite many reasons to focus exclusively on this era and to leave out other economies and Federal Reserve chairmen. We justify such a decision in greater detail in subsection 1.8, while later in section 3 we also present some grounds for nonlinearity and state-dependency in the monetary transmission mechanism which are specific to the Greenspan era. The literature, both theoretical and empirical, is extensive and sometimes covers very disparate aspects of Greenspan's Federal Reserve presidency which could have potentially influenced the shape of the monetary transmission mechanism during that period. Broadly speaking, evidence on some potential sources of nonlinearity and state-dependency is mixed, while in others it seems to be unequivocal.

The empirical part of this study begins in section 4, where we estimate a baseline linear model of the monetary transmission mechanism. In section 5 we employ the estimated model and develop a conservative testing procedure to show that the linearity and state-independency of the monetary transmission mechanism is a questionable assumption.

This justifies the next step we take in section 6, in which we exploit the $STAR$ framework (Teräsvirta 1994) to specify, estimate, select and evaluate nonlinear and state-dependent models of the monetary transmission mechanism.

Finally, in section 7 we analyse generalised impulse responses based on the $STAR$ models that were estimated in section 6, which allows us to verify the existence of sign, size and state asymmetries of the monetary transmission.

The analysis performed here detects statistically significant sign and size asymmetries, however, the obtained patterns of sign and size asymmetries are not robust among the estimated models. Therefore, in that respect we form methodological rather than empirical conclusions – we argue that a trustworthy analysis of sign and size asymmetries requires a framework which will identify both monetary policy shocks and their propagation mechanism at the same time. Developing such a framework in a nonlinear or state-dependent setting seems to be an interesting challenge for future research.

As far as state asymmetry is concerned, the econometric method employed here successfully identified the sources of state-dependency of the estimated equations and state asymmetry of the monetary transmission. The obtained results are justifiable from the theoretical perspective and useful in the context of conducting the monetary policy and scheduling monetary policy actions, though the Lucas critique should always be taken into consideration.

Traditionally, in the conclusions we once again sum up all of the findings and suggest some possible extensions or directions for future research in the area.

1. Defining basic concepts

1.1 Introduction

It is always good practice to clarify the terms which appear in the title of a study and may be, to some extent, ambiguous. Firstly we provide a basic intuition behind the concepts of nonlinearity, state-dependency and asymmetry, while later we explicitly define the concepts of nonlinearity, state-dependency and asymmetry, and thus introduce clear-cut distinction among them. Such a formalisation is motivated by very imprecise usage of these terms in the literature which, in our opinion, may potentially cause some misconceptions about the scope of this study. Since we are not interested in nonlinearity, state-dependency and asymmetry as independent and self-contained concepts, we want to refer to them in the context of the monetary transmission mechanism and impulse responses, thus we also define the latter two notions more precisely. Finally, we justify why we find the problem of nonlinearity and state-dependency of the monetary transmission mechanism which results in asymmetric impulse responses important and why we have chosen the Greenspan era as the period we want to analyse.

1.2 Preliminary considerations

As a preliminary intuition, nonlinearity, state-dependency and asymmetry of the monetary transmission may be perceived as a departure from the paradigm of modelling the monetary transmission with the use of linear and closed-system models which give rather mechanistic assessment of what the effects of the monetary policy shocks are.

Intuitively and nontechnically, a nonlinear relationship between two variables is 'a relation (...) that, when plotted on a graph, does not form a straight line' (Vogt and Johnson 2011) but – implicitly and most commonly – a curve. In other words, a nonlinear relationship is not directly proportional to the inputs, and unit effects of changing the input variable may vary along with the level of that variable.

By analogy, a state-dependent relationship between two variables may be depicted as a relation that, when plotted on a graph, forms a set of lines for different values of another variable rather than a single line. Put differently, the exact characteristics of a state-dependent relationship between two variables depend on the value of yet another variable. A model with interaction terms is a classic example of such a relationship.

An asymmetric relationship between two variables is a relationship that, when plotted on a graph, violates geometric symmetry i.e. a property of being invariant to a determined set of transforms (isometries) such as reflections, rotations or translations. Since there are many types of symmetries and corresponding transforms, one should specify exactly what types of asymmetry are taken into consideration, which we will do later in subsection 1.6.

Sometimes the concepts of nonlinearity, state-dependency and asymmetry are jointly labelled as the ‘non-linear’ approach[1] and since all the terms are used rather loosely (and confusingly) in the literature we find it very important to explicitly and precisely define them. Before doing so in the following subsections, however, we present an intuitive justification for why our considerations are not only of academic origin but also have practical policy oriented consequences.

According to the paradigm of modelling the monetary transmission with the use of linear and closed-system models the expected effects of monetary policy are always directly proportional to the magnitude of the monetary shock and invariant with respect to any other variables. In contrast, the ‘non-linear’ approach implies that the effects of monetary policy are sensitive to factors which are not usually taken into account by the standard models. In particular, raising the interest rate by e.g. 50 basis points is not necessarily equivalent to two hikes by 25 basis points and may have different absolute impact on the economy than cutting the interest rate by the same amount. Similarly, the effects of such a decision may vary along the business and financial cycle, or with the structural characteristics of the economy (e.g. labour share or trade openness) which evolve over time. In consequence, the central bankers face many strategic dilemmas regarding optimal scheduling of monetary policy actions. Intuitively, such a setting is much closer to the statement that ‘central banking is as much art as science’ (Blinder 1997) than the mechanistic perspective offered by the standard approach.

[1] Using the analogy of set theory (or logic), the ‘non-linear’ approach is the absolute (or logical) complement of the aforementioned paradigm of modelling monetary transmission with the use of linear and closed-system models.

1.3 Model of the monetary transmission mechanism

In this study we follow a general and very popular assumption that the model of the monetary transmission mechanism consists of three equations representing three endogenous variables: inflation (π_t), output gap (x_t), and short-term nominal interest rate (i_t). Conceptually, the equations correspond to the aggregate supply (Phillips curve) and aggregate demand (IS curve) sides of the economy and to the interest rate rule (Taylor rule), respectively. The endogenous variables depend on explanatory vectors ($\boldsymbol{z}_t^{\boldsymbol{\pi}}$, $\boldsymbol{z}_t^{\boldsymbol{x}}$ and $\boldsymbol{z}_t^{\boldsymbol{i}}$), which may include lagged, current and expected values of endogenous variables and some additional exogenous regressors. In particular, the basic New Keynesian model of monetary transmission fits into this definition as a special case.

Although the exchange rate equation is not included in our baseline model, we do not make a clear distinction between modelling a closed and open economy. As was shown in many papers (see e.g. Clarida, Galí and Gertler 2001, 2002; McCallum and Nelson 2000), explicit New Keynesian models of small open economy are usually isomorphic to the closed economy version of the model or can be reduced to such a form under some simplifying assumptions. Moreover, even if the model isomorphism may be questioned on theoretical grounds[2], both open- and closed- economy frameworks yield very similar responses of economic activity and inflation to domestic shocks not only for a relatively closed economy such as the U.S. (e.g. Erceg, Gust and López-Salido 2010) but also for a relatively open economy such as Canada (e.g. Dib 2011).

If we comply with the presented framework, nonlinearity and state-dependency of the monetary transmission mechanism may originate from every single equation constituting the model. Thus, after defining some fundamental concepts we firstly overview the existing literature on the general sources of nonlinearity and state-dependency at the equation levels and only then do we look at the monetary transmission mechanism as a system.

[2] see e.g. Barnett and Eryilmaz (2013) for a bifurcation analysis of the model developed by Clarida, Galí and Gertler (2002) or Corsetti, Dedola and Leduc (2010) for a unified analytical framework systematising the literature on optimal monetary policy in open economies.

1.4 Nonlinearity and state-dependency

As was suggested by Teräsvirta, Tjøstheim, and Granger (2010, Ch. 1.1), when writing about nonlinearity it might be a good idea to provide a precise definition of nonlinearity. Since finding the universal definition of nonlinearity is a more complex exercise than one could expect, we propose to follow a definition of nonlinearity in the conditional mean, which we find the most useful and adequate from the perspective of the investigated problem.[3]

In fact, it is more convenient to define linearity first and then to classify anything else as nonlinearity. The following definition is based on the one proposed by Teräsvirta, Tjøstheim, and Granger (2010, Ch. 1.1), and Lee, White and Granger (1993).

Definition 1

The model of the monetary transmission mechanism is said to be linear in the conditional mean if for any endogenous variable $y \in \{\pi, x, i\}$ depending on vector $\boldsymbol{z}_t^{\boldsymbol{y}}$ the conditional mean satisfies the following condition:

$$E\{y_t|\boldsymbol{z}_t^{\boldsymbol{y}}\} = \boldsymbol{\alpha}'\boldsymbol{z}_t^{\boldsymbol{y}} + g(\boldsymbol{z}_t^{\boldsymbol{y}}) \text{ and } g(\boldsymbol{z}_t^{\boldsymbol{y}}) \equiv 0$$

Then, if the above-mentioned condition is not satisfied it may be said that the model of the monetary transmission mechanism is nonlinear (in the conditional mean).

Intuitively, the given definition of nonlinearity implies that the conditional mean of at least one endogenous variable requires a nonlinear component, i.e. the conditional mean is something more than purely a linear combination of explanatory variables.

To make a clear distinction between linearity and nonlinearity in the conditional mean, let us imagine the four following models:

1. $y_t = \beta_0 + \beta_1 z_{1,t} + \beta_2 z_{2,t} + \varepsilon_{1,t}$
2. $y_t = \beta_0 + \beta_1 z_{1,t} + \beta_2 z_{2,t} + \beta_3 z_{1,t} z_{2,t} + \varepsilon_{2,t}$
3. $y_t = \beta_0 + \beta_1 z_{1,t} + \beta_2 z_{2,t} + \beta_4 {z_{1,t}}^2 + \varepsilon_{3,t}$
4. $y_t = \beta_0 + \beta_1 z_{1,t} + \beta_2 z_{2,t} + \beta_5 {z_{1,t}}^- + \beta_6 {z_{1,t}}^+ + \varepsilon_{4,t}$

   where $\beta_5 \neq \beta_6$, ${z_{1,t}}^- = \begin{cases} z_{1,t} & z_{1,t} \leq \bar{z}_1 \\ 0 & z_{1,t} > \bar{z}_1 \end{cases}$ and ${z_{1,t}}^+ = \begin{cases} z_{1,t} & z_{1,t} > \bar{z}_1 \\ 0 & z_{1,t} \leq \bar{z}_1 \end{cases}$

[3] See, e.g. Teräsvirta, Tjøstheim, and Granger (2010, Ch. 1.1) for some discussion on defining nonlinearity.

Although all of the models are linear in the estimated parameters, only the first model is linear in the conditional mean, i.e. all the others are nonlinear (in the conditional mean).

Similarly, it is also desirable to define the concept of state-dependency. To be coherent, we propose an analogous negative definition of state-dependency in the conditional mean.

Definition 2

The model of the monetary transmission mechanism is said to be state-independent in the conditional mean if for any endogenous variable $y \in \{\pi, x, i\}$ depending on vector $\boldsymbol{z}_t^{\boldsymbol{y}}$ and any variable $s_t \notin \{\pi, x, i, \boldsymbol{z}_t^{\boldsymbol{y}}, t\}$, the conditional mean satisfies the following condition:

$$E\{y_t | \boldsymbol{z}_t^{\boldsymbol{y}}\} \equiv E\{y_t | \boldsymbol{z}_t^{\boldsymbol{y}}, s_t\}$$

Then, if the above-mentioned condition is not satisfied it may be said that the model of the monetary transmission mechanism is said to be state-dependent (in the conditional mean) with respect to variable s_t.

The proposed definition reflects the basic intuition behind state-independency. If a model is state-independent then any additional variable beyond the variables already included in the model provides no extra information on the conditional mean of the endogenous variable or variables. In particular, it is convenient to think of state-independency as a situation when no estimated parameter (including constant[4]) is a function of any variable which is not included in the model (either as a dependent or independent variable). To make a clear-cut distinction between state-independency and time-independency, we also assume that s_t should not be a time variable (t), however, one may relax this assumption and claim that time-independency is just a particular case of state-independency. It would be convenient to name s_t as a 'state variable', but this could be misleading due to its meaning in the theory of dynamical systems and optimal control (as opposed to 'control variable'). Therefore, we avoid labelling the variable s_t or enclose the term 'state' in quotation marks.[5] Finally, it is also worth emphasising that the concept of state-independency is broader than the concept of structural invariance, and this does not necessarily imply that the estimated parameters are literally

[4] If a constant is the only parameter being the function of variable s_t, the problem of state-dependency with respect to s_t is reduced to a simple omitted variable problem.
[5] In specific econometric applications it could be labelled as, e.g. a switch(ing), transition or threshold variable.

constant in time since the definition allows for purely random fluctuations of the estimated parameters.

1.5 Impulse responses

Definitions of nonlinearity and state-dependency based on the concept of the conditional mean bring us directly to the problem of defining the impulse response function, which in this case becomes history- or state-dependent.

The standard impulse response function, known, e.g. from VAR models, can be expressed as the difference between the two conditional expected values:

$$IRF_{t+h}(y_t, \delta) = E\{y_{t+h} | \varepsilon_t^z = \delta, \varepsilon_{t+h}^z = 0\} - E\{y_{t+h} | \varepsilon_t^z = 0, \varepsilon_{t+h}^z = 0\}, \qquad h \in \mathbb{N}^+$$

Such an expression denotes the response of y_t to an impulse $\varepsilon_t^z = \delta$ in a variable z_t, in time $t + h$, i.e. h periods later after the one-off impulse has been initialised.

The concept works very well when we are dealing with models which are linear and state-independent in the conditional mean. In such a case the impulse response is always proportional to the size of the initial shock, and independent of the history prior to when the shock was initialised and to the 'external' circumstances in which propagation of the shock takes place. In other words, even if the impulse response function were formally conditioned on the historical or actual values of some variables, these terms would be analytically zeroed out. In consequence, all we need to calculate the impulse response function is to know the estimated model. Once the model is estimated, we no longer need any data because the impulse response functions becomes an analytical property of the estimated model itself.

A problem arises when we analyse models which are nonlinear or state-dependent in the conditional mean. Bearing in mind definitions 1 and 2, the impulse response now becomes a function of the historical or actual values of some variables and it is no longer necessarily proportional to the size of the initial shock.

It might be appealing that we should extend the formal definition of the impulse response function, so the expected values are additionally conditioned on the historical or actual values of relevant variables (the term denoted as ω_t):

$$IRF_{t+h}(y_t, \delta, \omega_t) = E\{y_{t+h} | \varepsilon_t^z = \delta, \varepsilon_{t+h}^z = 0, \omega_t\} - E\{y_{t+h} | \varepsilon_t^z = 0, \varepsilon_{t+h}^z = 0, \omega_t\}, h \in \mathbb{N}^+$$

However, as was shown by Teräsvirta, Tjøstheim, and Granger (2010, Ch. 15.1), such an amendment is insufficient since it leads to a bias in the impulse response function due to the assumption that all future shocks are equal to zero ($\varepsilon_{t+h}^z = 0$ for $h \in \mathbb{N}^+$).[6]

That is why Koop, Pesaran, and Potter (1996) developed the generalised impulse response function allowing for both non-zero future shocks and conditioning on the historical or actual values of relevant variables. The generalised and bias-corrected version of the impulse response function may thus be expressed as:

$$GIRF_{t+h}(y_t, \delta, \omega_t) = E\{y_{t+h} | \varepsilon_t^z = \delta, \omega_t\} - E\{y_{t+h} | \omega_t\}, \qquad h \in \mathbb{N}^+$$

Since $\varepsilon_t^z = \delta$ is a single preset value of an innovation to z_t, and ω_t is a single path of the values of some relevant variables, the obtained generalised impulse response should be treated as just a single realisation of a random variable. Therefore, if we want to capture some universal properties of the impulse response we should rather look at the densities of generalised impulse response functions:

$$\boldsymbol{GIRF}_{t+h}(y_t, \varepsilon_t^z, \Omega_t) = E\{y_{t+h} | \varepsilon_t^z, \Omega_t\} - E\{y_{t+h} | \Omega_t\}, \qquad h \in \mathbb{N}^+$$

In such a notation ε_t^z represents shocks of a certain type, while Ω_t refers to the set of all the possible (or applicable) historical or actual values of relevant variables (usually $\Omega_t = \{\omega_{t-j} : j \in \mathbb{N}^0\}$). Because both ε_t^z and Ω_t are random, obtaining densities of general impulse response functions requires appropriate sampling techniques.

[6] In the case of nonlinear function $E\{f(\varepsilon_{t+h})\} \neq f(E\{\varepsilon_{t+h}\})$, so even if it is true that $E\{\varepsilon_{t+h}\} = 0$, conditioning the expected value of y_{t+h} on $\varepsilon_{t+h} = 0$ for $h \in \mathbb{N}^+$ creates a bias in both the minuend and subtrahend of the impulse response function. Since the model is nonlinear, the errors generally do not equalise, which results in a biased specification of the impulse response function. Analogously, it is not necessarily true that $E\{f(y_{t+h}) | s_t\} = f(E\{y_{t+h} | s_t\})$, and a similar bias may arise as a result of the model's state-dependency.

1.6 Asymmetry of the monetary transmission

Even though there is a number of various concepts and definitions of asymmetry (see e.g. Verbrugge 1997; Ramsey and Rothman 1996), they usually refer to single time series or univariate models. If asymmetry in the macroeconomic-type model is investigated, the idea of asymmetry is usually expressed in terms of a model functional form and inequalities of some model parameters (single equation models), or less precisely in a verbal form (single and multi-equation models). The latter typically states that the standardised reaction of an endogenous variable to changes in the explanatory variables may vary (i.e. be asymmetric) with respect to the sign and size of this change and the value of some other variables.

In our opinion this may lead to some misunderstandings, since it is not perfectly clear whether asymmetry should be perceived as an analytical property of the estimated functional form of the model or rather as some patterns observed in the empirical densities of impulse response functions. We argue that this dilemma is not trifling and that the latter approach is much more favourable, at least in the case of our research.

First, the term 'asymmetric function' may be misleading and equivocal. In mathematics, symmetric function is a multivariable function which is invariant to any permutation of its variables. On the other hand, the econometric concept of asymmetry is intuitively related to functions which are not: odd or even (sign asymmetry), homogeneous of degree one (size asymmetry) or additively separable (state asymmetry). This, however, may again create some ambiguities and requires that one specify whether one means properties of the functional form of: the conditional mean, the marginal effect or the partial effect.[7]

Second, bearing in mind the risk of misspecification and overfitting, it is desirable to look at a discrete space of values which took place in reality rather than in a hypothetical and continuous domain as suggested by the functional form of the model.

Finally, in the context of multi-equation models, where due to interactions among all the endogenous variables different sources of asymmetry may amplify or restrain one another, it can be difficult to describe the asymmetry in terms of the analytical properties of the functional form of the estimated system. This would require knowing closed-form solutions

[7] Imagine a function $E\{y|x\} = x^2$ which is even but not homogeneous of degree one. The marginal effect $\frac{\partial E\{y|x\}}{\partial x} = 2x$ is odd and homogeneous of degree one, while the partial effect (for $\Delta x = \varepsilon$) $\frac{\Delta E\{y|x\}}{\Delta x} = 2x + \varepsilon$ is neither odd/even nor homogeneous of degree one.

for all the endogenous variables although in some cases only numerical solutions may exist or be obtainable in practice.

Taking the above negative motivation into consideration we propose to make a clear distinction that although nonlinearity and state-dependency of the monetary transmission are properties of a model functional form, asymmetry of the monetary transmission is a property of generalised impulse response functions.[8] Such an approach allows us to avoid the presented ambiguities and simplifies not only the definition of asymmetry of the monetary transmission but also its operational usage. Thus, we define asymmetry of the monetary transmission in terms of densities of generalised impulse response functions, which is – as far as we know – the first time such a definition of various types of asymmetry has formally and explicitly been put forward.

Definition 3

The monetary transmission is said to be symmetric if for any endogenous variable $y \in \{\pi, x, i\}$ *and for any variable* z_t *being an element of vector* $\boldsymbol{y_t} = [\pi_t, x_t, i_t]'$, $\boldsymbol{z_t^{\pi}}$, $\boldsymbol{z_t^{x}}$ *or* $\boldsymbol{z_t^{i}}$ *densities of the generalised impulse response functions satisfy the following conditions:*

1. $|\boldsymbol{GIRF}_{t+h}(y_t, \varepsilon_t^z > 0, \Omega_t)| = |\boldsymbol{GIRF}_{t+h}(y_t, -\varepsilon_t^z < 0, \Omega_t)|, \qquad h \in \mathbb{N}^+$
2. $\boldsymbol{GIRF}_{t+h}(y_t, \varepsilon_t^z, \Omega_t) = \frac{1}{\kappa}\boldsymbol{GIRF}_{t+h}(y_t, \kappa\varepsilon_t^z, \Omega_t), \qquad h \in \mathbb{N}^+, \kappa \in \mathbb{R}^+$
3. $\boldsymbol{GIRF}_{t+h}(y_t, \varepsilon_t^z, \Omega_t^1) = \cdots = \boldsymbol{GIRF}_{t+h}(y_t, \varepsilon_t^z, \Omega_t^I)$,

   where $\Omega_t^i \in \{\Omega_t^i \subset \Omega_t : DR(\omega_{t-j}), \bigcup_{i=1}^{I} \Omega_t^i = \Omega_t, \bigcap_{i=1}^{I} \Omega_t^i = \emptyset, \Omega_t^i \neq \emptyset\}$;
   $DR(\omega_{t-j})$ *stands for a division rule being a function that associates a single path* ω_{t-j} *to a corresponding subset* Ω_t^i *according to some logical conditions;* $I \in \{2, \dots, |\Omega_t|\}$; *and* $h, j \in \mathbb{N}^+$

Then, if any of the above-mentioned conditions is not satisfied it may be said that the monetary transmission is asymmetric. In particular, violating the respective conditions corresponds to:

1. *sign asymmetry*
2. *size asymmetry*

[8] It is important to emphasise that the chosen conceptualisation of asymmetry at the level of the monetary transmission mechanism as a system of equations does not exclude a ‘traditional definition’ of asymmetry at the level of individual equations constituting the monetary transmission mechanism.

3. *state asymmetry (with respect to the applied division rule).*

The presented definition is very general but at the same time distinguishes three different types of asymmetries.

Sign asymmetry implies that densities of generalised impulse responses vary for positive and negative shocks. In the context of the monetary transmission we are particularly interested in comparing the effects of expansionary and restrictive monetary policy impulses.

Size asymmetry means that standardised densities of generalised impulse responses depend on the size of the shock. In this paper we focus our attention on comparing the unit effects of small and big monetary policy impulses.

State asymmetry entails that densities of generalised impulse responses are neither history nor state invariant. In the proposed definition a set of all possible histories (Ω_t) is divided into a declared number of collectively exhaustive and mutually exclusive non-empty subsets in accordance with some division rule[9]. If the densities of generalised impulse responses are equal to one another for all of the identified subsets then the model is (state) symmetric. Otherwise, there is state asymmetry with respect to the applied division rule. Exceptionally, one could also compare densities of generalised impulse response functions for all single paths of ω_{t-j} – on the one hand, this does not require specifying any division rule, but on the other it does not allow to identify potential sources of state asymmetry. As far as the monetary transmission is concerned, we would like to know whether e.g. the effects of monetary impulses vary along different phases of the monetary policy and business cycles and whether they depend on some structural characteristics of the economy.

1.7 Why is it important?

One may wonder whether nonlinearity and state-dependency of the monetary transmission mechanism resulting in asymmetric impulse responses are something more than academic

[9] One could also imagine the most extreme version of the proposed definition in which it is required that densities of generalised impulse response functions are equal to one another for all partitions of a set Ω_t. This would, however, involve comparing the Bell number of densities of generalised impulse response functions, which quickly goes beyond any reasonable threshold (e.g. there are 115975 and 1382958545 partitions of a set of 10 and 15 elements, respectively; see more in the On-Line Encyclopedia of Integer Sequences OEIS, sequence A000110: http://oeis.org/A000110).

curiosities and whether research in this area may somehow be useful in the policy-making process. If the answer is negative, why should we care and complicate our linear or log-linearised models of the monetary transmission mechanism?

First, nonlinear and state-dependent models imply that uncertainty is an inherent nature of the monetary transmission mechanism. Even if our model were the real data generating process and we knew the exact numerical values of all the parameters (not only their estimates), there would still be room for uncertainty due to the fact that for nonlinear functions: $E\{f(\varepsilon_{t+h})\} \neq f(E\{\varepsilon_{t+h}\})$ and $E\{f(y_{t+h})|s_t\} \neq f(E\{y_{t+h}|s_t\})$. In other words, central bankers would still have to deal with the density of generalised impulse response functions rather than a single and deterministic pattern of impulse response.

Second, as was suggested in the previous subsection, in the case of a nonlinear and state-dependent setting of the monetary transmission mechanism, a standardised (i.e. divided by the size and sign of a shock) response of the economy to a monetary policy impulse may exert asymmetries and depend on the:

- sign of the impulse (expansionary or restrictive)
- size of the impulse (gradualism or cold turkey)
- phase of the monetary policy (tightening, loosening or stabilising monetary conditions)
- phase of the business cycle (expansions or contraction – 2 stages; boom, slowdown, recession or recovery – 4 stages)

Such a feature of the monetary transmission mechanism gives more importance to thoughtful scheduling of monetary policy impulses than in the linear case, because improper timing and dosing may create deadweight costs in terms of lower output or higher inflation. Then central bankers face a set of strategic and interrelated dilemmas, e.g. they:

- act pre-emptively (to avoid larger costs in the future) or ‘wait and see’ (to avoid a possible mistake) if an important change in economic conditions is expected
- smooth the interest rate path or accept contrary swings in interest rates if economic conditions change abruptly
- act gradually or serve a cold turkey if it is desirable to reach some interest rate target
- act whatever the macroeconomic conditions are or wait for a more favourable moment.

What is more, central bankers' faulty decisions may not be as easily reversible as in the linear case, which provides additional incentives to conduct a reliable monetary policy.

The two remarks justify why central banks should put much effort in forecasting and projecting economic outcomes under different scenarios and sets of assumptions. The more we know about the future, the smaller the uncertainty will be regarding the exact shape of the impulse response function and the easier it will be to conduct a desirable monetary policy.

One may also perceive the above-mentioned findings as a model-based depiction of the aforementioned statement that 'central banking is as much art as science' (Blinder 1997). When there is inherent uncertainty in a model describing the monetary transmission mechanism and there are many strategic dilemmas regarding conducting a monetary policy, there is also much space for experts' knowledge and intuition which go beyond simple quantitative relationships captured by the model's equations.

1.8 Why the Greenspan era?

Obviously, any empirical researcher faces the choice of an adequate sample to be analysed in line with the research agenda. As was previously noted, the aim of this paper is to verify the existence of nonlinearity and state-dependency of the monetary transmission mechanism resulting in asymmetric impulse responses. At the same time, it was emphasised that we are not interested in extremely turbulent periods, such as pre-World War II recessions (in particular the Great Depression) or the recent Great Recession, when breaking linearity and state-independency assumptions would not be surprising. Additionally, there are also some methodological and practical limitations which should be taken into consideration when choosing the sample. In particular, nonlinear modelling requires possibly long but coherent time series which should not include additional sources of structural changes in the estimated relationships, apart from those captured by the employed econometric method. Bearing in mind these conditions, we have decided to focus our attention solely on the Greenspan era and to leave other economies and Federal Reserve presidencies aside.

Choosing the U.S economy results from great availability of the modern economic literature on the monetary transmission in the United States. This facilitates the process of searching for sound premises behind nonlinearity and state-dependency of the monetary transmission mechanism resulting in asymmetric impulse responses. Such a property is all the more important since the research departs, to some extent, from the standard assumptions of the mainstream economics, and papers in that field are very scarce in the case of other economies.

The selection of one particular tenure decreases the risk of significant breakpoints between different Federal Reserve chairmen (e.g. as was suggested in subsection 2.4) and makes the analysed sample more coherent. To be more transparent we also list more precise arguments supporting our choice of the Greenspan era:

- As requested, the Greenspan era did not coincide with the largest recessions in the U.S economic history and it ended before the outburst of the Great Recession.
- Greenspan chairmanship lasted more than 18 years (from 11 August 1987 to 31 January 2006), which is the second-longest tenure after Martin, who tenured 4 months longer (from 2 April 1951 to 1 February 1970).
- Availability of data is greater for the Greenspan era than for previous Federal Reserve presidencies (especially when compared to Martin's tenure – e.g. data on the federal funds rate is available from July 1954, which makes the effective 'Martin' sample shorter than the 'Greenspan' one).
- As was suggested by Bernanke and Mihov (1998), throughout the whole sample of the Greenspan era the federal funds rate is an appropriate measure of the monetary policy (in contrast to 1979-1982, when non-borrowed reserves were more informative on the monetary policy stance due to the 'Volcker experiment').
- Throughout the whole sample the U.S. dollar exchange rate was free-floating against main currencies (e.g. in the Bretton Woods system, 1944-1971/1973, occasional sudden changes in peg rates took place, which immediately affected the economy's international competitiveness).

Although the selection of a sample is always to some extent subjective, we argue that the choice of the Greenspan era as the period to be analysed herein is in line with our research agenda and provides a reasonable compromise between the longitude of time series and their coherency. At the same time it also gives a chance to investigate sources of nonlinearity and state-dependency of the monetary transmission mechanism which may be seen as very specific or even endemic to the Greenspan era.

1.9 The aim and scope of this study

The main aim of this study is to verify the existence of nonlinearity and state-dependency of the monetary transmission mechanism in the Greenspan era. We expect that the standard assumption of linearity and state-independency of the monetary transmission mechanism will be broadly rejected by the adopted procedure of econometric modelling and testing. Since nonlinearity and state-dependency of the monetary transmission mechanism both result in various types of asymmetry of impulse responses, we are also interested in verifying the existence of sign, size and state asymmetries of the monetary transmission. Similarly, we expect to obtain statistically significant and robust patterns of asymmetry of the monetary transmission, which would question the convention of treating impulse responses as symmetric ones.

The scope of the study is quite general and empirical. We use a possibly broad set of data against which we test the assumptions of linearity and state-independency of the monetary transmission mechanism and the symmetry of impulse responses. The analysed theoretical concepts serve as a background for both the selection of potential sources of nonlinearity, state-dependency and asymmetry, and for interpretation of the obtained results. Nevertheless, it is worth emphasising that we do not aim to empirically examine specific theoretical concepts which predict nonlinearity or state-dependency of the monetary transmission mechanism. The idea is rather to employ a unified econometric framework as to obtain comparable assessment of the importance of many heterogeneous sources of nonlinearity, state-dependency and asymmetry. Such results may later be employed to designate the most promising areas of future research.

1.10 Summary

In this section we defined the concepts of nonlinearity and state-dependency of the monetary transmission mechanism and various types of asymmetry of impulse responses. We will base our discussion on these definitions throughout the rest of the text. Moreover, we also justified why we find the problem important and why we have chosen the Greenspan era as the period we want to analyse. Finally, we specified precisely the main aim and scope of the study. In the following section we discuss the general premises behind nonlinearity and state-dependency of the monetary transmission mechanism resulting in asymmetric impulse responses.

2. General premises behind nonlinearity and state-dependency of the monetary transmission mechanism

2.1 Introduction

In this section we discuss the general premises justifying nonlinearity and state-dependency of the monetary transmission mechanism. We start by considering both the theoretical and empirical aspects, at the level of every single equation constituting the monetary transmission mechanism (i.e. the Phillips curve, the IS curve and the Taylor rule), and only later shall we tackle both the monetary transmission mechanism as a system and the issue of asymmetric impulse responses. The premises considered here are general in the sense that they do not refer to any particular timespan or economy but have a more universal application. This contrasts with the next section, in which we analyse premises which are specific to the Greenspan era and may have much more limited relevance for other periods or economies.

2.2 Aggregate supply side – the Phillips curve

2.2.1 Introduction to the nonlinear and state-dependent Phillips curve

The original work by Phillips (1958) and some Keynesian follow-ups (e.g. Lipsey 1960; Hansen 1970) presented the Phillips curve in a nonlinear form. Also, in influential papers by Phelps (1967, 1968) the Phillips curve was expressed in at least potentially nonlinear terms. It was probably the simplified textbook version of the Phillips curve which gave rise to drawing the Phillips curve as a straight line without explicitly mentioning that originally it was indeed a curve. Later the development of New Keynesian economics and a dynamic stochastic general equilibrium framework legitimated a linear form of the Phillips curve via log-linearising models around the steady-state. Undoubtedly, practical and technical reasons played a crucial role in the process.

Without loss of generality most of the analysed and estimated forms of the Phillips curves can be nested in the following model[10]:

[10] We follow the convention of treating the Phillips curve as a relation between the output gap and inflation, not between unemployment and the rate of change of nominal wages or inflation. However, a short historical note should do justice:
It was Fisher (1928, 1973), not Phillips (1958), who carried out the first known empirical study on the relationship between unemployment and inflation. Moreover, since the original paper by Phillips (1958) presented the relationship between unemployment and the rate of change of nominal wages it was not until

$$\pi_t = \alpha + \beta_0 E_t\pi_t + \beta_1 E_t\pi_{t+1} + \sum \gamma_i \pi_{t-i} + \sum \delta_i x_{t-i} + \boldsymbol{\theta z_t} + \varepsilon_t \tag{1.1}$$

where:

π_t	– inflation rate
$E_t\pi_t$	– inflation rate at time t expected at time t (backward-looking expectations)
$E_t\pi_{t+1}$	– inflation rate at time $t+1$ expected at time t (forward-looking expectations)
x_t	– output gap
$\boldsymbol{z_t}$	– additional regressors.

In particular, imposing appropriate restrictions on the parameters in (1.1) delivers the aforementioned New Keynesian Phillips Curve (1.2) and Hybrid New Keynesian Phillips curve (1.3), as known from the influential paper by Galí and Gertler (1999):

$$\pi_t = \beta E_t\pi_{t+1} + \delta x_t + \varepsilon_t \tag{1.2}$$

$$\pi_t = (1-\gamma)E_t\pi_{t+1} + \gamma\pi_{t-1} + \delta x_t + \varepsilon_t \tag{1.3}$$

A common feature of all linear and state-independent forms of the Phillips curve nested in (1.1) is that they imply constant short-run trade-off between the output gap and inflation. This means that disinflation costs are invariable and equal to the potential gains from equivalent increasing inflation. As a result, the monetary policy is not able to influence the average level of economic activity but only its variance, and there is no obviously preferable way of conducting disinflation.

Such a suggestion is at odds with empirical findings, which show that the sacrifice ratio is not necessarily constant in time and may vary along with the economic conditions. Clark and McCracken (2006) showed that estimates of the coefficients on the output gap are instable, while Ball (1994) and Jordan (1997) found that the sacrifice ratio is smaller when disinflation

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Samuelson and Solow (1960) reformulated the Phillips curve into a relationship between unemployment and inflation as was initially proposed by Fisher (1928). Later, dissemination of 'Okun's law' (Okun, 1962) and groundbreaking papers by Phelps (1967, 1968), Friedman (1968) and Lucas (1972, 1973) popularised the expectations-augmented (short-term) Phillips curve expressed as a relation between the output gap and inflation. Finally, a combination of dynamic stochastic general equilibrium modelling as was introduced by Kydland and Prescott (1982), microfounded macroeconomic models with monopolistic competition (e.g. Blanchard and Kiyotaki 1987; Ball and Romer 1990) and nominal rigidities (e.g. Taylor 1979, 1980; Rotenberg 1982 and especially Calvo 1983), topped with a seminal paper by Galí and Gertler (1999), gave birth to New Keynesian and hybrid New Keynesian Phillips curves (NKPC and HNKPC, respectively) in which expectations are forward-looking.

is done quickly and to some extent when the initial level of inflation is high. Both results put together mean that the Phillips curve is probably nonlinear or state-dependent and there is a strong need for both micro-based concepts which are able to bear the non-constant sacrifice ratio and empirical evidence on the exact shape of the Phillips curve.

2.2.2 Micro-based concepts behind nonlinearity and state-dependency of the Phillips curve

There are quite a few theoretical concepts which lead to the nonlinear or state-dependent Phillips curve and the sacrifice (or gain) ratio as being a function of some (macro)economic conditions. For simplicity we group these ideas into eight main categories, describe some important models which belong to those categories and shortly discuss their fundamental properties[11]. In some cases we also analyse their implications for the monetary policy. It should be noted, however, that the distinguished categories are very often closely interrelated and that some models or concepts fit into more than one category. The aim of the survey is to point to some distinctive strands in the literature rather than to rigorously classify all of the concepts and models according to some explicit rules.

(1) In the *capacity constraint* model (see e.g. Mackleem 1997), enterprises are unable or find it costly to increase their production capacity in the short run. If they face a positive aggregate demand shock they are more willing to increase production rather than prices when capacity utilisation is low. On the other hand, when the capacity constraint becomes binding, enterprises are not able to increase production to satisfy demand at a given price level, so the optimising behaviour involves increasing prices. In consequence, the model implies that the Phillips curve is convex, which is consistent with the empirical findings presented originally by Phillips (1958).[12]

Convexity of the Phillips curve means that disinflation costs are smaller when the economy is overheated, while gains from increasing inflation are larger when the economy is far below its capacity constraint. Furthermore, convexity of the Phillips curve justifies why central banks

[11] The survey of concepts is a very extended, generalised and updated version of the one presented by Dupasquier and Ricketts (1998), who distinguished only five models: the *capacity constraint* model, *misperception* or *signal extraction* model, *costly adjustment* model, *downward nominal wage rigidity* model and the *monopolistically competitive* model.

[12] Hansen and Prescott (2005) showed that in their RBC model with occasionally binding capacity constraints the business cycle is asymmetric – the peaks are smaller than the troughs.

should smooth business cycles – the smaller the variance of output, the greater its average level. As was pointed out by Mackleem (1997) and Dupasquier and Ricketts (1998), by taking lags in the monetary transmission mechanism into consideration, the model also gives some incentives for conducting a pre-emptive monetary policy to prevent overheating of the economy because then the inflation becomes highly reactive to demand shocks and may be explosive. This intuition is also supported by Clark, Laxton and Rose (2001), who found forward-looking policy rules superior to myopic ones in the presence of a capacity constraint.

(2) As was previously mentioned, *misperception* or *signal extraction* models (e.g. Lucas 1972, 1973) result in a Phillips curve, the slope of which depends positively on the variance of inflation. Since relative and absolute price shocks are not directly observable, an enterprise needs to assess to which extent the change in the market price of its good is due to the shift in real and nominal demand. In the first extreme case the optimising behaviour implies increasing production, while in the second one – increasing prices. However, the more volatile inflation is, the more difficult the signal extraction problem is to be solved and the larger part of a single price shock is assigned to the change in nominal demand, which results in increasing prices rather than increasing production.

The model predicts that disinflation costs are smaller when the inflation is volatile, while gains from increasing inflation are larger when it is stable. Moreover, the model implies a trade-off between stabilising nominal and real variables, thus smoothing the business cycle comes at the expense of allowing for more volatile inflation.

Rational inattention models (e.g. Maćkowiak and Wiederholt 2009, 2011) extend the problem of signal extraction on the limited information-processing abilities of agents who allocate their attention among idiosyncratic and aggregate conditions according to the information flow constraint. Optimising behaviour implies that firms pay relatively more attention to more volatile shocks, which means that increasing volatility of nominal shocks makes real output less responsive to a particular nominal shock. However, the effect of increasing the average size of a shock is large enough to raise the volatility of real output. Thus, although implications for the shape of the Phillips curve, disinflation costs and gains from raising inflation are the same as in the case of the Lucas model, the two models differ markedly with respect to the relation between volatilities of nominal and real variables. In particular, rational inattention models imply that stabilising nominal variables helps to smooth the business cycle, which is at odds with the Lucas model.

(3) *Costly adjustment* models assume that changing prices or wages creates some costs which prevent enterprises from adjusting prices or wages if the distance between the actual and optimal level is not large enough to make such a move profitable.

In the presence of *menu costs*, both the frequency and size of such adjustments depend positively on the level of inflation (see e.g. Ball, Mankiw and Romer 1988; Ball and Mankiw 1994). Thus the higher the inflation is, the more responsive it is to demand shocks.

Dupasquier and Ricketts (1998) argued that a similar relationship arises when negotiating wage contracts is costly. Then it might be reasonable to condition the duration of wage contracts on the expected level of inflation – the higher it is, the shorter are the contracts and the more frequently they are renegotiated. In both cases the slope of the Phillips curve is positively related to the average level of inflation and inflation expectations. Moreover, the Phillips curve might be convex in the presence of trend inflation.

According to Dupasquier and Ricketts (1998), the two models provide some incentives to follow the 'wait and see' strategy. Since disinflation is more costly when the average level of inflation is already low and it takes more time for a demand shock to transform into inflation than otherwise, central bankers have incentives to act cautiously and unhurriedly, which should allow them to gather more information about the state of the inflationary pressure.

Burstein (2006) extended the problem of *menu costs* (*sticky prices*) on *dynamic pricing plans* (*sticky pricing plans*) by allowing firms to choose an entire sequence of future prices rather than a single price. Similarly, in such an environment the Phillips curve is convex – disinflation is less costly when the initial level of inflation is high while the actual (i.e. at a single point of the Phillips curve) sacrifice ratio is greater than the gain ratio. The monetary authorities, however, have even more time to react to inflationary pressure than in a standard menu cost model because a firm is not forced to 'front-load', i.e. to raise its actual price before the expected change in the economic conditions materialises.

(4) *Downward wage rigidity* models propose that, due to some institutional conditions and behavioural factors, wages are more rigid downward than upward. In consequence, when output gap or inflation expectations are low the Phillips curve may be less steep (and possibly convex) than otherwise.

(4a) Downward wage rigidity usually refers to *downward nominal wage rigidity*. Then wages are not only more rigid downward than upward but it is also easier to lower wages via increasing inflation than via cutting real wages. In such an environment, central bankers have strong incentives to avoid not only very high but also very low levels of inflation since then, as was shown by Akerlof, Dickens and Perry (1996), significant welfare loss may occur even in the long run. If there is an economic downturn and real wages are inefficiently high, raising inflation (though very unwelcome by public opinion) could be the only way to quickly regain the competitiveness of the economy. This justifies why the inflation target should be above zero and why temporary high inflation (i.e. above the targeted level) may sometimes be desirable.

The most popular explanation as to why nominal but not real wages might be rigid downward is some form of *money illusion* which ‘seems to be widespread among economic agents and can be systemically studied and modelled’ (Shafir, Diamond and Tversky 1997). Apart from the most extreme and most controversial form of money illusion, i.e. when agents do not distinguish between nominal and real terms, it also includes *fairness attitudes*, according to which cuts in nominal wages are seen by employees as more unfair than equivalent cuts in real wages.

(4b) The above-mentioned *fairness attitudes* may be seen as an abutment where theories of downward nominal wage rigidity meet the theories of *downward real wage rigidity. Implicit contract* theories of employment (see e.g. Stiglitz 1984b or Snowdon and Vane 2005, Ch. 7.7.2) treat an employment agreement as some form of wage and employment insurance – since employers are usually less risk averse and have better access to capital markets than employees, so downward wage rigidity is offered to the latter at the expense of lower average wage. However, since this theory fails to explain lay-offs during economic downturns and says nothing about why employees are not underbid by the unemployed, it is not perceived as a complete theory of real wage rigidity. *Efficiency wage* theories[13] fill this gap by proposing that ‘the (net) productivity of workers is a function on the wage paid’ (see e.g. Stiglitz 1984b). Then it might be counterproductive for a firm to cut wages unless this is absolutely necessary. Finally, *insider-outsider* models (Lindbeck and Snower 1986, 1988) focus on the insiders’ (employees’) power to gain some rent resulting from the various turnover costs and risks associated with hiring outsiders (the unemployed). Since many of these costs directly depend

[13] Snowdon and Vane (2005, Ch. 7.7.2) described four such theories: the *adverse selection* model, the *labour turnover* model, the *shirking* model and the *fairness* model.

on the attitude and behaviour of the insiders, they possess a true bargaining power which prevents the employer from cutting wages and/or hiring new employees with lower wage expectations. All three theories are capable of delivering wages which might be rigid downward in both real and nominal terms[14], while the last two also justify the phenomenon of involuntary unemployment.

The consequences of downward real wage rigidity are much more profound for the monetary policy than in the case of nominal rigidity. In extreme circumstances (full-upward and null-downward indexation of wages), at every point of time central bankers face the vertical and horizontal 'Phillips curve' for expansionary and restrictive actions respectively, which virtually means that no action should be taken at all because it will always be wealth-deteriorating. In a more moderate world the Phillips curve is steeper upward than downward while the difference between the two might be a decreasing function of the inflation level, which should induce the monetary authorities to act responsively and swiftly rather than pre-emptively or gradually. However, real wage rigidity calls into question whether the monetary policy is truly able to promote both price stability and full employment at the same time. This is all the more doubtful because – according to theories of real wage rigidities – involuntary unemployment seems to be the rule rather than the exception.

(5) Models of *firms' strategic behaviour in an imperfectly competitive environment* show how prices could be instruments and information signals in market games among competing and/or cooperating firms. In this case the exact shape of the Phillips curve depends on the market structure and relative incentives to cut or raise prices in response to demand and cost shocks.

(5a) Dupasquier and Ricketts (1998) argued that in the *monopolistically competitive* model firms may have strong incentives to avoid being undercut by competitors since they then lose consumers. Thus, whenever possible they are eager to be the first to lower prices and the last to raise them. In such an environment the Phillips curve is concave, which means that smoothing the business cycle deteriorates wealth, while central bankers may push an economy to the limit of capacity constraints without creating too much additional inflationary pressure.

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[14] Although all three theories are usually categorised as theories of real wage rigidity (see e.g. Snowdon and Vane 2005, Ch. 7.7.2), they result in a mix of downward nominal and real wage rigidity. The exact proportions depend on whether implicit contracts are 'expressed' in real or nominal (or both) terms, productivity of workers is a function of real or nominal (or both) wages, and insiders have enough bargaining power to acquire at least partial indexation of wages.

On the other hand, when an economy is overheated, deflationary actions come at a larger cost than otherwise.

(5b) Stiglitz (1984a) delivered a model in which *limit pricing* may serve as an efficient *entry deterrent*. Since during expansions the threat of new entry is more pronounced than during recessions, incumbents might be inclined to apply the policy of countercyclical markups. Certainly the shape of the Phillips curve also depends on the cyclical properties of marginal costs, but under some plausible assumptions the Phillips curve might be concave, as in the model described by Dupasquier and Ricketts (1998).

(5c) In the same paper Stiglitz (1984a) provided some anecdotal evidence on markets with asymmetric information, where the price level serves as an instrument coordinating *collusive behaviour*. Because firms do not observe each other's demand curves, they are not able to judge whether lowering a price below a cooperative level is fair or not. Thus, any undercutting of a cooperative price is treated as breaking the agreement. If there is no cap on raising prices they are more rigid downward than upward, and the Phillips curve may have similar properties as in the case of downward real wage rigidity.

(5d) Rotemberg and Woodford (1991) argued that markets may exhibit *procyclical competitiveness*. As the economy grows there is enough room for more competitors on the market, and thus any oligopolistic or implicit collusions from the recession period are more difficult to maintain. In consequence, the Phillips curve may be steeper during expansions than during recessions and possibly convex.

(6) *Imperfect credibility* models (see e.g. Alichi et al. 2009) assume that some parameters of the Phillips curve might be endogenous from the perspective of the central bank. In particular, the credibility of the central bank, which is at least partially manageable by its authorities, may influence the extent to which expectations are backward- and forward-looking. Thus the shape of the Phillips curve may depend on variables influencing the central bank's credibility. Although it might be difficult to specify an exhaustive set of such variables, one should expect the average level and variance of inflation (or deviation from the inflation target if applicable) and economic activity to be among them.

Moreover, in the presence of imperfect credibility, central bankers may face having the sacrifice ratio be larger than the gain ratio at every single point of time and the Phillips curve be convex upward but concave downward. In such an environment central bankers should act pre-emptively in order not to lose 'the stock of credibility', since any delay and deterioration of credibility may raise the sacrifice ratio and lower the gain ratio. Isard, Laxton and Eliasson (2001) proved that in the presence of endogenous credibility, forward-looking monetary policy rules are superior to backward-looking ones.

(7) Models of *consumers' behaviour* and *strategic interactions between consumers and firms* focus on typical imperfections on the consumers' side of the market and their implications for consumer-firm relations. Commonly, emphasis is put on the limited information that is available to consumers and/or on information asymmetries between consumers and firms. In some cases, however, it is proposed to enrich the otherwise standard economic model with some behavioural aspects of human behaviour. Thus, implications for the shape of the Phillips curve (and monetary policy) are model-sensitive.

(7a) *Customer markets* are described as markets where the frequency of purchase is much larger than the frequency of search due to significant costs of the latter resulting in limited information on the lowest prices in the marketplace (Snowdon and Vane 2005, Ch. 7.7.1). Such a description typically suits markets of fast-moving consumer goods (FMCG) or retailers offering a wide assortment of various goods (e.g. supermarkets), where firms may have some monopolistic power despite there being many other companies offering similar products or services. Since shopping is usually done quite frequently and regularly, firms have strong incentives to discourage consumers from exploring the market in search of lower prices. Thus, they avoid raising prices or at least being the first to do so. On the other hand, even though lowering prices attracts new customers, firms are less eager to do so than in the monopolistically competitive model as was described by Dupasquier and Ricketts (1998), because significant costs of the search delay the consumers' response. Therefore, in such an environment the Phillips curve may be concave, but less concave than in the above-mentioned monopolistically competitive model.

(7b) Stiglitz (1984a) put forward a generalisation of the above-mentioned *model with costly search*. He argued that in many situations it is not obvious whether the discouraging effect is bigger than the encouraging effect. A costly search creates a kink in the demand curve as faced by firms, but the location of this kink is crucial to the direction of relative price rigidity. In some cases, the costs of the search might be large enough in relation to the frequency of the purchase to create downward price rigidity, and then the Phillips curve is convex.

(7c) It is a well-known phenomenon that in the presence of imperfect information consumers may use the heuristic *judging quality by price* (e.g. Stiglitz 1984a, 1987; Allen 1988). Then, intuitively, firms have additional incentives to avoid price cuts and may be inclined to win both higher markup and reputation by raising prices. In consequence, prices may be rigid downward and possibly explosive upward while the Phillips curve should be convex.

(7d) Snir et al. (2012) presented some evidence on the importance of *pricing points* (Kashyap 1995) with respect to 9-ending prices, which may serve imperfectly informed consumers as signals for low prices. Strategically responsive retailers tend to disguise a price increase by setting a 9-ending price. At the same time, experiments show that setting a 9-ending price does not help consumers to notice a price cut, probably because retailers have many more effective instruments to signal price cuts. Therefore, in the presence of low inflation the Phillips curve may be steeper downward than upward and possibly concave.

(7e) Chen et al. (2008) argued that the aforementioned rational inattention may lead to a *asymmetric price adjustment in the small*. Since consumers rationally decide not to pay attention to small price movements, retailers have stronger incentives to slightly raise rather than to slightly cut prices. By analysing a large price dataset, Chen et al. (2008) found that 'small price increases occur more frequently than small price decreases', even if various measures of inflation are taken into account. In consequence, the Phillips curve may be steeper upward than downward and possibly convex for low levels of inflation.

(7f) Rotemberg (2002) proposed a model in which *customers' anger* at price increases creates upward rigidity of prices. The result is obtained by applying the 'psychological utility function', which includes not only individual payoffs but also fairness of prices. If a price is considered to be unfair, a customer stops purchasing to 'punish' the firm. Although the presented model predicts concavity of the Phillips curve, it should be noted that the outcomes are highly sensitive to the fairness definition and distribution of information among customers and firms. In particular, the shape of the Phillips curve may be state-dependent and determined by macroeconomic variables as observed by consumers, since fairness of prices may be judged with respect to actual economic conditions.

(7g) Similarly, as in the case of downward wage rigidity, asymmetric price adjustment may be the result of *implicit contracts* between enterprises and customers. The combination of customers' dislike for frequent price changes (see e.g. Okun 1981; Kahneman, Knetsch and Taler 1986) and the aforementioned costly search may induce a firm to offer an *implicit* contract in which it promises to, for example, keep the price constant for a given period of time or until some trigger will allow the firm to renegotiate the contract or offer a new one. In practice, the contract works as insurance against undesirable price increases while a higher markup is a risk premium. Asymmetric price adjustment arises because the firm is punished twice for a price increase, while the positive effect of a price cut may offset the negative effect of a price change. Thus the Phillips curve should be steeper downward than upward. However, such a situation is likely to happen only when inflation is stable at a low level. Otherwise, either customers or enterprises would probably not be interested in such a contract. In consequence, the difference between the upward and the downward slope should eventually disappear as inflation rises.

(7h) Bils (1989) built a model delivering *procyclical elasticity of demand* (for durable goods). The procyclicality arises because low-income customers who exhibit more elastic demand than high-income customers drop out of the market in recessions and re-enter it as the economy grows. Blinder (1994) stated that procyclicality of demand elasticity may also be justified by a segmentation of customers with respect to their loyalty. During recessions a firm maintains its most loyal customers but loses the least loyal ones, who eventually come back when the economy recovers. As a result, the elasticity of demand is procyclical which, similarly as in the case of procyclical competitiveness[15], makes the Phillips curve steeper during expansions than during recessions and possibly convex.

(8) *Macroeconomic externalities* and *coordination failures* play a fundamental role in the New Keynesian theory of the business cycle and are widely exploited in analyses of price stickiness and macroeconomic stability (Snowdon and Vane 2005, Ch. 7.7).

In a typical New Keynesian model of the business cycle, *aggregate demand externalities* and *coordination failure* arise from a combination of an imperfectly competitive market and either adjustment costs (e.g. Blanchard and Kiyotaki 1987, Ball and Romer 1991) or, less commonly, '*near rationality*' of economic agents (e.g. Akerlof and Yellen 1985a, 1985b). In such an environment an individual decision to change (or not) the level of prices influences the optimal decisions of other firms due to *strategic complementarity*, i.e. an effect which is

[15] The concepts of procyclical competitiveness and procyclical elasticity of demand were developed to fit into the observed pattern of countercyclical markups over marginal cost, thus both may be perceived as theories of *countercyclical markups*.

not internalised by individual firms. Thus, prices are sticky because each firm has no individual incentive to change the price first and waits for other firms to do so first.

Interestingly, if real rigidities are great enough, the coordination failure may lead to multiple equilibria in the degree of price rigidity and multiple short-run equilibria of the economy, some of which are superior to others (Ball and Romer 1991).[16] This intuitively gives welfare-based justification for policies aimed at pushing the economy towards the Pareto better equilibrium. However, the main problem associated with multiple equilibria models is that one cannot assess the effects of the monetary (or any economic) policy unless one particular equilibrium is chosen, and usually there is no justification for any specific selection (Rotemberg 1987). Moreover, since the outcome in multiple equilibria models is not fully determined by fundamental variables and crucially depends on the agents' expectations, it is very sensitive to any *animal spirits, self-fulfilling prophecies* and *sunspots* (Romer 2012, Ch. 6.8). Thus, either the Phillips curve is non-existent or its shape is not only state- but also 'sunspot-dependent'.

Even if the coordination failure is not strong enough to create a multi-equilibrium environment, it can make the equilibrium *fragile* (Summers 1988). Then the equilibrium is unique, but any factor that even slightly shifts the reaction function greatly affects the economy *via* the multiplier effect. Thus the shape of the Phillips curve may still be state-dependent.

Parallel results arise in models with a costly search if the search cost is a decreasing function of economic activity or size of the market. In his seminal paper, Diamond (1982) showed that, under this plausible assumption, strategic complementarity creates *thick market externalities,* because the positive effects of a bigger market (lower cost search) are not fully internalised by individual firms. Similarly, as in the case of aggregate demand externalities, coordination failure may lead to multiple equilibria prone to animal spirits, self-fulfilling prophecies and sunspots, or a unique but fragile equilibrium.

It should be noted that the above-mentioned models of coordination failure in demand and trade should be treated simply as examples of this phenomenon. Romer (2012, Ch. 6.8) writes that since coordination failure is very closely related to real rigidities, and there are many potential sources of real rigidity, then there are also many potential coordination failures that are consistent with a general framework as was presented by Cooper and John (1988). Indeed,

[16] The second outcome holds even if prices are perfectly flexible (Cooper and John 1988).

some other models of coordination failure include externalities in, for example, employment (e.g. Kaplan and Menzio 2013) or investment (e.g. Shleifer and Vishny 1988).

The literature overview presented here shows that there are many micro-based premises suggesting a nonlinear and state-dependent reaction between economic activity and inflation. Although most of the aforementioned papers present, or at least redirect to, some empirical evidence in favour of the proposed theoretical concepts, it is difficult to assess the relative importance of all of them. According to the survey conducted by Blinder (1994)[17], probably many theories are at play at the same time. Some of them tend to be more frequently accepted by the enterprises as relevant (see Table 1), but, as far as we know, there is no comprehensive study gathering all concepts in one place.

Table 1.1 Percentage of enterprises accepting various theories of price stickiness

Coordination failure – each firm waiting for others to change price first	60.6
Implicit contracts – fairness to customers necessitates stable prices	50.4
Costly price adjustment – menu cost	30.0
Procyclical elasticity – demand curves become more inelastic as they shift to the left	29.7
Psychological significance of pricing points	24.0
Judging quality by price – fear that customers will interpret a reduction in price as a reduction in quality	10.0

Source: Adapted from Snowdon and Vane (2005, Ch. 7), and Blinder (1994)

The findings of the survey do not even allow to sketch the general shape of the Phillips curve since the most popular theories among enterprises have different predictions in that respect (see Table A.1.1 in Appendix A.1 for a short summary). That is why it is worth reviewing the results of empirical studies with a more aggregate perspective.

2.2.3 Empirical evidence on nonlinearity and state-dependency of the Phillips curve

Since empirical literature on the shape of the Phillips curve is extensive and there are many studies for various countries, herein we focus on the implications for the U.S. economy in accordance with our research agenda[18]. Such a choice is also justified by a presumption that country-specific factors (e.g. the structure of the economy, labour market regulations) may

[17] The aim of the survey was to verify the existence and to assess the relative importance of various theories of price stickiness, not micro-based concepts behind the nonlinearity or state-dependency of the Phillips curve. Thus Table 1 presents only a selection of the theories investigated by Blinder (1994).

[18] As previously, we turn our attention only to studies treating the Phillips curve as a relation between inflation and the output gap.

play an important role in determining the shape of the Phillips curve and thus may blur the overall picture. A detailed overview of studies is presented in Table A1.2 in Appendix A.1.

At first glance, the main findings of the papers surveyed here are inconsistent. Yates (1998) found no evidence in favour of nonlinearities in the Phillips curve; Turner (1995), Clark, Laxton and Rose (1996), and Clements and Sensier (2003) suggested its convexity; Saglio and López-Villavicencio (2012) – concavity, while Filardo (1998) detected both convexity and concavity of the Phillips curve for the positive and negative output gap, respectively. Moreover, Saglio and López-Villavicencio (2012) disclosed the state-dependency of the Phillips curve with respect to trend inflation, its variance and capacity utilisation – the slope of the Phillips curve is very flat for low and stable inflation and steep for a high level of capacity utilisation.

However, it is very important to stress that the results are very sensitive to the econometric approach that is applied. Estimation of a kinked or threshold piecewise linear function with one kink or one threshold is not potent to deliver a mixed concave-convex shape of the Phillips curve, and Filardo (1998) is the only author who applied the kinked piecewise linear function with two kinks which allowed for more complex forms of nonlinearity. On the other hand, state-dependency of the Phillips curve was investigated only by Saglio and López-Villavicencio (2012) and to some extent by Yates (1998). Thus, one should be particularly aware that in most cases the lack of evidence in favour of some particular form of nonlinearity or state-dependency results from the limitations of the method that is employed[19].

Laxton, Rose and Tetlow (1993) emphasised the great importance of the output gap measure for the accuracy of nonlinearity tests. By using Monte Carlo simulations applied to a specified small model which incorporates nonlinearity of the relation between inflation and output they showed that simple detrending methods (including the HP filter) impair statistical inference against finding the nonlinearity of the Phillips curve. What is more, such a result occurs despite the assumption that the exact functional form is estimated. Bearing in mind that all but one of the investigated papers measured the output gap only with the HP filter, one may expect that the true degree of nonlinearity of the Phillips curve is underestimated.

[19] Searching for particular forms of nonlinearities and state-dependency is also very prone to the problem of induction – 'absence of evidence is not evidence of absence'.

2.3 Aggregate demand curve – the IS curve

2.3.1 Introduction to the nonlinear and state-dependent IS curve

Although there are probably more papers dealing with the effects of the monetary policy on output than on inflation, the IS curve has likely received less attention in the economic literature than the Phillips curve[20]. The situation seems to be all the more surprising since this is the IS curve which establishes a direct link between the monetary policy instrument (nominal short-term interest rate) and the system of equations in a typical small model of monetary transmission.

Whatever the reason for the above-mentioned state of affairs, usually estimated forms of the IS curve can be nested in the following general model:

$$\begin{aligned} x_t = {} & \alpha + \beta_0 E_t x_t + \beta_1 E_t x_{t+1} + \sum \gamma_i x_{t-i} + \\ & + \sum \delta_i (i_{t-i} - E_{t-i}\pi_{t-i+1} - r^*_{t-i}) + \boldsymbol{\theta z_t} + \varepsilon_t \end{aligned} \tag{1.4}$$

where:

x_t	– output gap
$E_t x_t$	– output gap at time t expected at time t (backward-looking expectations)
$E_t x_{t+1}$	– output gap at time $t+1$ expected at time t (forward-looking expectations)
$E_{t-i}\pi_{t-i+1}$	– inflation rate at time $t-i+1$ expected at time $t-i$
i_t	– nominal short-term interest rate
r^*_{t-i}	– natural real interest rate (usually treated as a time invariant parameter)
$\boldsymbol{z_t}$	– additional regressors.

Similarly as in the case of the Phillips curve, imposing appropriate restrictions on the variables and parameters in (1.4) yields the New Keynesian IS Curve in purely forward-looking (1.5) and hybrid (1.6) settings as known from the seminal paper by Clarida, Galí and Gertler (1999):

$$x_t = E_t x_{t+1} + \gamma(i_t - E_t \pi_{t+1}) + \varepsilon_t \tag{1.5}$$

$$x_t = \beta x_{t-1} + (1-\beta) E_t x_{t+1} + \gamma(i_t - E_t \pi_{t+1}) + \varepsilon_t \tag{1.6}$$

[20] See Table A1.6 in Appendix A.1 for the results of the simple ‘searching’ experiment.

As was pointed out by Stracca (2010), the New Keynesian IS curve suffers from a severe lack of robust empirical support and it does not seem to be a structural relationship despite its sound theoretical background which is based on a DSGE framework. In particular, instability of the estimated parameters makes the IS curve prone to nonlinearity and state-dependency. The issue is of utmost importance in the context of the already mentioned suggestion (see subsection 1.6) that the standardised response of output to monetary policy actions is not necessarily constant in time and may depend on certain conditions. Therefore, as in the case of the Phillips curve, we firstly discuss the theoretical micro-based concepts behind the nonlinearity or state-dependency of the IS curve and later we show some empirical results on the issue.

2.3.2 Micro-based concepts behind nonlinearity and state-dependency of the IS curve

Since the IS curve equation typically incorporates the inflation expectations term (see equation 1.4), nonlinearity and state-dependency of the Phillips curve may be perceived as one of the (indirect) sources of nonlinearity and state-dependency of the IS curve even if the IS equation is linear with respect to both the estimated parameters and the explanatory variables. Otherwise, the literature on the micro-based concepts behind nonlinearity and state-dependency of the IS curve itself is scarce when compared to the Phillips curve and builds on five main premises:

(1) As was suggested by Keynes in his breakthrough *The General Theory of Employment, Interest and Money* (1936), in a crisis situation and/or when nominal interest rates are already at very low levels, any further loosening of the monetary policy may fail to boost the economy due to the *liquidity trap*. In such a situation economic agents exhibit strong liquidity preference which, in the original notion, lowers or completely breaks up the responsiveness of interest rates to changes in money stock. In a modern setting the liquidity trap is usually seen as a potential consequence of the *zero lower bound* on the nominal interest rate as an instrument of the central bank.[21] However, the *flight to liquidity* seems to be more frequent behaviour than only when the central bank interest rate is at a near-zero level. In particular, Vayanos (2004) proposed a model in which the liquidity premium increases with aggregate

[21] The concept will be discussed later in the context of nonlinearities and state-dependency of the Taylor rule.

volatility, while Longstaff (2004) showed that the liquidity premium is positively correlated with various market sentiment measures.

In the presence of financial distress, not only flight to liquidity but also *flight to quality* is observed on money and capital markets. The phenomenon arises when market participants turn their interest into very safe assets and try to disengage from riskier investments due to higher effective risk aversion.[22] Longstaff, Mithal and Neis (2005), and Beber, Brandt and Kavajecz (2008) claimed that a major part of the variance of the spread among bonds (corporate and sovereign, respectively) is explained by default risk, but in the presence of market distress, investors seek liquidity rather than quality. Nevertheless, it is worth noting that flight to liquidity and flight to quality might be difficult to distinguish in practice. Moreover they may result not only from market-driven mechanisms but also from some institutional factors e.g. capital and liquidity requirements imposed by regulators.

Flight to liquidity and quality induces banks to lower the supply of credit in favour of more liquid and safe assets and to change the composition of credit towards a short-term and less risky credit. In an extreme case the credit market becomes completely clogged and irresponsive to changes in interest rates, as depicted by the *pushing a string* metaphor.

Therefore, the output might be relatively irresponsive to changes in central bank interest rates in periods of market distress, and the slope of the IS curve[23] may negatively depend on a number of variables being the symptoms or proxies of market distress. Borio (2004) argued that managing liquidity crises with standard measures of the monetary policy, though usually helpful, is not sufficient and comes at a cost of moral hazard and risk of overreaction. Indeed, Krishnamurt (2010) showed that both preventing and resolving liquidity crises may require measures which go beyond simply easing the monetary policy. Taylor (2009) claimed that even measures which are usually successful in solving liquidity crises are by far insufficient when the counterparty risk is an underlying cause of market distress.

(2) According to the *credit channel theory* (Bernanke and Gertler 1995), tightening the monetary policy and lowering economic activity have a deteriorating impact on the financial situation of both banks and enterprises. In the first case (*bank lending sub-channel*), it eventually lowers the supply of intermediated credit that is available to potential borrowers

[22] It may result from both higher objective risk aversion and higher perceived risk.
[23] In contrast to a typical textbook IS-LM model, the IS equation is expressed as an output gap (y-axis) function of the interest rate (x-axis).

and tightens credit conditions, while in the second one (*balance sheet* or *net worth sub-channel*) it downgrades the creditworthiness of enterprises and pushes ‘low-quality’ ones out of the credit market due to credit rationing.[24] Blinder (1987) developed a model with credit rationing (see e.g. Stiglitz and Weiss 1981) and predicted that the monetary policy has a stronger impact on economic activity when credit conditions are tight, while Bernanke, Gertler and Gilchrist (1996) presented a model with a balance sheet channel in which restrictive monetary policy shocks are likely to have a more pronounced impact on economic activity than expansionary ones.

Therefore, the existence of a credit channel suggests that the slope of the IS curve may be inversely related to credit conditions in the economy. Since tight credit conditions usually coincide with a recession rather than an expansion, one may also expect that the IS curve should be more steep, especially downwards, in the first case. The aforementioned nonlinearity and state-dependency may induce central bankers to be relatively more expansionary in a recession than suggested by a typical Taylor rule, since any tightening of the monetary policy or premature exit from an expansionary phase of the monetary policy may increase the risk of prolonged or double-dip recession.

(3) Although technically the following considerations refer to the LM curve, *an asymmetric and incomplete interest rate pass-through*, i.e. a mechanism which drives a wedge between the policy rate and the market rate(s), may be perceived as a source of nonlinearity and state-dependency of the IS curve.[25] Interestingly, the explanations of macroeconomic asymmetries in interest rate pass-through usually originate either from the credit channel theory and the concepts which are closely related to flight to liquidity and quality or models of banks’ strategic behaviour in an imperfectly competitive environment and strategic interactions between banks and customers (see e.g. Sznajderska 2013).

In the first case it is expected that during periods of economic downturn and market distress the interest rate pass-through might be impaired which should result in flattening of the IS curve.

[24] Since ‘low-quality’ enterprises usually have very limited access to money and capital markets, their exclusion from the credit market may actually result in the deprivation of any external financing.
[25] This discrepancy arises because in standard models it is usually assumed that the central bank is able to control the market interest rate(s) with the use of the central bank’s official interest rate (the LM curve is equivalent to Taylor rule), while the essence of incomplete pass-through is that it allows for relaxing such an assumption.

In the latter case, analogously as in the matter of the Phillips curve and points (5) and (7) in paragraph 2.2.2, the theoretical predictions are highly sensitive to the structural characteristics of the market. In general, lower levels of competition (e.g. Gambacorta and Iannotti 2007; Gropp, Kok, and Lichtenberger 2014) and higher levels of information asymmetry between banks and customers (e.g. Rosen 2002) are assigned to a more impaired pass-through and a flatter IS curve. Since economic expansion creates positive macroeconomic externalities which foster competition and lower search costs (see point (8) in 2.2.2), one may expect that the slope of the IS curve is an increasing function of economic activity.

Roelands (2012) showed that liquidity and capital requirements established by regulators may result in asymmetric interest rate pass-through. In particular, when the central bank lowers the official interest rate, the probability that banks become constrained rises. As a result, banks may decide to adjust their rates only partially and increase markups. By analogy, the opposite situation takes place when the monetary policy is tightened. The presented mechanism is consistent with the empirical findings that 'banks tend to increase interest rates on loans at roughly the same speed as the reference rate, but lower their rates at a slower pace' and 'pass-through often appears to be less complete during falling rate periods relative to rising rate periods' (Roelands 2012). In consequence, the IS curve should be steeper upward than downward and possibly convex.

(4) Bloom (2009) showed that *uncertainty shocks* not only generate a sharp decline in economic activity but also temporarily freeze the propagation of the monetary (and fiscal) policy. A stalemate arises because uncertainty makes firms extremely irresponsive to changes in interest rates, prices or wages. On the other hand, when uncertainty eases, impulses are propagated more vigorously but with some lag. Therefore, the slope of the IS curve may be state-dependent with respect to uncertainty – as it rises the slope becomes flatter and when the uncertainty goes down the IS curve steepens. The uncertainty shocks increase the risk of monetary policy overreaction since temporal irresponsiveness of the economy may mislead central bankers and induce them to act more aggressively since they see no immediate effects of moderate actions. At the same time, a sensible exit strategy is required to avoid swinging the economy.

(5) Tversky and Kahneman (1992) extended the baseline *prospect theory* (Kahneman and Tversky 1979) into the *cumulative prospect theory* which incorporates making decisions

under risk and uncertainty. Bowman, Minehart and Rabin (1999) showed that in such a framework consumers may be relatively irresponsive to negative shocks because they want to avoid consuming less than their reference point if only possible. In the context of the IS curve this means that the slope of the IS curve may be flatter for restrictive than expansionary monetary shocks and, similarly, the coefficient on the expected output gap might be larger for positive than negative output gaps. Therefore, once consumers get used to higher consumption expenditures and a higher reference point is established, the monetary policy may be relatively ineffective in cooling down the economy. The threat of such a situation is particularly large during long periods of (overheated) prosperity.

The survey of the literature presented here delivers a prediction of the state-dependent IS curve, the slope of which may depend on market sentiment, credit conditions, uncertainty, the stance of the monetary policy and the level of economic activity. It should be, however, noted that the presented concepts predict multidirectional relations between the slope of the IS curve and the phenomena which are closely interrelated and very often concurrent. Therefore the expected overall shape of the IS curve is somewhat ambiguous from theoretical perspective, especially if we consider complex economic and financial crises when virtually all of the above-mentioned phenomena take place at the same time. It is possible that standard monetary policy measures may come across very serious difficulties in both reviving the economy during recessions (as pointed out by concepts (1)-(4)) and cooling it down during expansions (as pointed out by concept (5)). Nevertheless the overall shape of the IS curve remains to be an empirical problem. The next paragraph reviews the empirical studies which help to balance the effects described here.

2.3.3 Empirical evidence on nonlinearity and state-dependency of the IS curve

As was already mentioned, in the literature the IS curve receives much less interest than the Phillips curve. Although there are many papers which explicitly aim to empirically verify the existence of nonlinearity and state-dependency of the latter, to our knowledge no such studies have yet been performed for the IS curve (neither for the U.S nor any other economy). Nevertheless, there are two strands in the literature which are closely related to the problem investigated here.

The first one was already preannounced and verifies whether the New Keynesian IS curve is truly a structural relationship and whether the estimates of its parameters are stable. Stracca (2010) claimed that 'the New Keynesian IS curve, at least in its most common formulations, is not structural and is overwhelmingly rejected by the data'. In particular, the coefficient on the real interest rate is usually insignificant or wrongly signed[26] and the estimates of the parameters in the IS curve tend to differ for groups of countries with different basic structural characteristics (size of the economy, trade openness, share of industry in GDP, ratios to GDP: NFA, liquid liabilities, private credit, stock market capitalisation, household debt, household net worth, household short-term net worth). Therefore, the results suggest that the IS curve may be state-dependent and its most common linear form is not structural in the sense of Lucas (1976).

The second strand in the literature is focused on the shape of the impact of monetary policy shocks on economic activity, and its overview is presented in Table A1.3 in Appendix A.1[27]. Although at first glance such a research agenda may seem to be an equivalent description of investigating the shape of the IS curve, it is not for reasons of identification problems. In other words, unless a nonlinear or state-dependent version of the IS curve is estimated, any evidence in favour of an asymmetric reaction of economic activity to monetary policy shocks should be treated at most as consistent with the nonlinear or state-dependent IS curve.

Particularly, there are at least three caveats which arise as a consequence of the usually adopted empirical method according to which the estimated equation has an ad hoc empirical form where a measure of economic activity is an endogenous variable while lags of the endogenous variable and measures of monetary policy shocks are regressors:

- economic activity is usually measured with growth rates of GDP, GNP or industrial production (not with the output gap as predicted by the IS curve)
- there is no inflation nor inflation expectations among explanatory variables as required by the IS curve
- there is no interest rate among explanatory variables but monetary policy shocks which are derived from auxiliary regressions of the money stock or interest rate (two-step regression instead of estimating a structural relationship).

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[26] Goodhart and Hofmann (2005) argued that a significantly negative impact of the real interest rate on economic activity is restorable if one allows for a richer specification of the IS curve, including asset prices and monetary aggregates.

[27] As previously, we focus on the U.S. economy.

Bearing in mind the above-mentioned remarks, the literature surveyed here shows that the link between monetary policy shocks and economic activity is asymmetric. A vast majority of the papers (Cover 1992; DeLong and Summers 1988; Kakes 1998; Karras and Stokes 1999; Lo and Piger 2005; Morgan 1993; Sim 2009) provided robust evidence that restrictive monetary policy shocks exert a larger impact on economic activity than expansionary ones, while some authors (Cover 1992; DeLong and Summers 1988; Karras and Stokes 1999; Morgan 1993; Ravn and Sola 2004) even found that expansionary monetary policy shocks are impotent to significantly affect the output. Moreover, Garcia and Shaller (2002) and Lo and Piger (2005) noticed that the effects of monetary policy shocks are stronger in a recession than in an expansion. When put together, the observed links between monetary policy shocks and economic activity suggest that standard monetary policy measures may be relatively ineffective in both boosting the economy in a recession and cooling the economy in an expansion.

Although the results invoked here are consistent with previously presented concepts behind the nonlinear and state-dependent IS curve, they are also coherent with the convex and state-dependent Phillips curve. Karras and Stokes (1999), who estimated both the output and price equations to verify the relative importance of the two sources, claimed that their study 'implies that neither of the two theories individually can fully explain both the output and price effects, but it suggests that both have to be operative at the same time.' Thus, even if nonlinearity and state-dependency of the IS curve are not the only source of the detected links between monetary policy shocks and economic activity, they play an important role in explaining some of the patterns observed in the data.

In conclusion, the two aforementioned strands in the literature jointly point to significant nonlinearity and state-dependency of the IS curve. In particular, the parameters of the IS curve seem to depend on both some structural characteristics of the economy and the stage of the business cycle.

2.4. The Taylor rule

2.4.1 Introduction to the nonlinear and state-dependent Taylor rule

In 1992, at the 39th Carnegie-Rochester Conference on Public Policy, Taylor (1993) proposed a simple but representative interest rate rule for the monetary policy which could be rewritten as:

$$i_t = r^* + \pi^* + 0.5x_t + 1.5(\pi_t - \pi^*) \qquad (1.7)$$

where:

i_t	– nominal short-term interest rate
r^*	– natural real interest rate (equal to 2 according to Taylor's proposition)
π^*	– desired inflation rate (equal to 2 according to Taylor's proposition)
x_t	– output gap
π_t	– inflation rate

Over the years, many extensions and modifications have been proposed to tackle various empirical and theoretical issues related to the original Taylor rule (for an extensive survey see e.g. Hamalainen 2004). Without loss of generality, most of the analysed and estimated forms of the Taylor rule can be nested in the following model:

$$i_t = \alpha + \sum \beta_i i_{t-i} + \sum \gamma_i \pi_{t-i} + \sum \delta_i x_{t-i} + \sum \vartheta_i E_t \pi_{t+i} + \sum \mu_i E_t x_{t+i} + \\ + \boldsymbol{\theta} \boldsymbol{z_t} + \varepsilon_t \qquad (1.8)$$

where:

i_t	– nominal short-term interest rate
π_t	– inflation rate
x_t	– output gap
$E_t\pi_{t+i}$	– inflation rate at time $t+i$ expected at time t (forward-looking expectations)
$E_t x_{t+i}$	– output gap at time $t+i$ expected at time t (forward-looking expectations)
$\boldsymbol{z_t}$	– additional regressors

As previously, imposing appropriate restrictions yields purely forward-looking and 'smoothed' versions of the Taylor rule as known from Clarida, Galí and Gertler (1999, 2000):

$$i_t = \alpha + \vartheta E_t \pi_{t+1} + \delta x_t + \varepsilon_t \quad (1.9)$$

$$i_t = \alpha + \beta i_{t-1} + \vartheta E_t \pi_{t+1} + \delta x_t + \varepsilon_t \quad (1.10)$$

Alternatively, even in New Keynesian models it is also very popular to present the Taylor rule in forms which are closer to its original version and in which inflation expectations are substituted with the current inflation rate.

$$i_t = \alpha + \vartheta \pi_t + \delta x_t + \varepsilon_t \quad (1.11)$$

$$i_t = \alpha + \beta i_{t-1} + \vartheta \pi_t + \delta x_t + \varepsilon_t \quad (1.12)$$

Although the Taylor rule was originally proposed as a simple and representative monetary policy rule without very formal justification, Clarida, Galí and Gertler (1999) showed that its New Keynesian versions can be derived as optimal policy rules in a broad class of models. In the next paragraph we discuss how relaxing some assumptions behind that exercise is potent to delivering significant nonlinearity and state-dependency of the (otherwise linear) Taylor rule.

2.4.2 Micro-based concepts behind nonlinearity and state-dependency of the Taylor rule

As was shown by Clarida, Galí and Gertler (1999), New Keynesian versions of the Taylor rule can be derived under the assumption of quadratic loss function of the central bank subject to constraints given by the linear and structural equations of the Phillips curve and the IS curve. Intuitively, the derived Taylor rule is linear because the Phillips curve and the IS curve are assumed to be linear. If one allows for nonlinearities or state-dependency of the curves, similar properties emerge in the derived Taylor rule as a result of the optimising behaviour of the central bank. Otherwise, there are at least five general concepts which question some of the assumptions made by Clarida, Galí and Gertler (1999), and thus justify the nonlinear or state-dependent Taylor rule.

(1) Cukierman and Muscatelli (2008) claimed that there is both anecdotal and systematic evidence of *non-quadratic loss function of central bankers*. In particular, they distinguished two types of *asymmetries in the policymakers' preferences* – recession and inflation avoidance preferences. In the first case, central bankers are more averse to negative than

positive output gaps, while in the second case the opposite applies for inflation gaps (i.e. the difference between the actual and targeted inflation rate). In consequence, the Taylor rule is either concave or convex in both gaps (respectively). The authors found strong empirical support in favour of the concept, however, 'the dominant type of asymmetry in monetary policy [...] often changes with the economic environment' and the tenures of central bankers.

Furthermore, al-Nowaihi and Stracca (2002) called into question the other two assumptions underlying the typically employed loss function of monetary policymakers. Relying on the economic psychology literature, they suggested that agents commonly show a tendency to *non-convex loss function* and *nonlinear weighing of probabilities*, thus departing from the expected utility paradigm. In general, any of the two postulates is potent to break the principle of certainty equivalence, which consequently leads to the inclusion of higher than first-order moments of output and inflation gaps in the optimal monetary policy rule. Although its shape crucially depends on the nature of the shocks and the exact form of the adopted non-convex loss function, the predicted Taylor rule is nonlinear.

(2) Orphanides and Wilcox (2002) proposed a formal model of *the opportunistic approach to disinflation* according to which policymakers wait for favourable external circumstances if the actual inflation moderately exceeds the long-term targeted level but act aggressively when inflation goes up too far. 'Reverse engineering' allows them to show that such behaviour is consistent with an otherwise typical linear-quadratic model of the economy if the central bankers' intermediate inflation target is history-dependent. Then the optimal policy rule is state-dependent and piecewise linear with respect to inflation. Aksoy et al. (2006) demonstrated that such a policy achieves disinflation at a lower output cost than a conventional one, but it takes more time to bring down inflation to the long-term target. Martin and Milas (2006) provided empirical evidence in favour of the behaviour predicted by the concept.

Similarly, Orphanides and Wieland (2000) derived a model in which the monetary authorities pursue *inflation zone-targeting* or *inflation targeting with a thick inflation target*. Then, taking into account the uncertainty, the optimal policymakers' response to inflation is very mild if inflation is below or above the zone-target midpoint but within the zone, and more pronounced when inflation is out of bounds. The general idea is explicitly supported with the legal framework of some central banks, while Tashibana (2008) also provided some econometric evidence for the U.S.

(3) As was pointed out by Swanson (2006), when deriving the optimal policy rule it is typically assumed that 'stochastic shocks and policymakers' prior beliefs about unobserved variables are normally distributed'. Meyer, Swanson and Wieland (2001), and Swanson (2006) showed that if one allows for *uncertainty about the level of economic activity*, *non-normality of central bankers' priors* and *Bayesian updating* in an otherwise standard model of the economy, the optimal interest rate rule is nonlinear. In particular, the monetary authorities are relatively more irresponsive to small than large output gaps due to the signal extraction problem. Swanson (2006) claimed that the basic idea of the concept is empirically supported by both model-based and anecdotal evidence; for example, the problem of uncertainty about the natural rate of employment or potential output, and continuous updating of their estimates, is explicitly put forward in official statements by the monetary authorities.

(4) By a similar token, Tillmann (2011) argued that the nonlinearity of the Taylor rule can be justified with the *model's parameters uncertainty* combined with the *robust control approach* (Hansen and Sargent 2007). It is proposed that in the presence of uncertainty of parameters regarding the monetary transmission mechanism (herein the slope of the Phillips curve), 'central banks want to formulate robust policies that are to some extent immune with respect to model disturbances' (herein minimising the costs of the worst-case scenario). In consequence, 'the policy response to inflation becomes stronger, the higher the inflation rate and the larger the output gap'. Similarly as Swanson (2006), Tillmann (2011) showed that his predictions are in line with both model-based (econometric) and anecdotal evidence (e.g. Greenspan 2004).

(5) Although there are some historical episodes of negative interest rates[28], it is generally accepted that the short-term nominal interest rule, being the primary instrument of the monetary policy, should not be pushed below zero (see e.g. Bernanke, Reinhart and Stack 2004). Intuitively, in the presence of the *zero lower bound* on interest rates, nonlinearity of the Taylor rule develops automatically as the interest rate is forbidden to adjust below zero, even if such an adjustment would be required by an otherwise linear rule (e.g. during recession or deflation). However, Adam and Billi (2007) showed that incorporating the *zero lower bound* into the optimising behaviour of economic agents has much more pronounced consequences and yields a highly nonlinear optimal policy rule, according to which the interest rates should

[28] E.g. in July 2009 Sveriges Riksbank lowered its deposit rate to -0.25%.

be reduced aggressively if the risk of reaching the zero lower bound is high (in response to a negative shock). The result arises because 'rational agents anticipate the possibility of reaching the lower bound in the future and this amplifies the effects of adverse shocks well before the bound is reached'.

Commonly, a situation when the *zero lower bound* is strictly binding is referred to as a *liquidity trap* in parallel to Keynes' term for a situation when the expansionary monetary policy is impotent to boost the economy. As was noticed by Krugman (1999), and Eggertsson and Woodford (2003), there are two basic ways to lower the real interest rate, and even if the nominal interest rate is bounded at zero the real interest rate can be lowered *via* rising inflation expectations. In particular, the central bank may raise inflation expectations and thus stimulate aggregate demand with *forward guidance*, i.e. a credible promise to keep a lower interest rate path than suggested by the traditional policy rule despite improving economic conditions. Therefore, nonlinearity or state-dependency of the Taylor rule may also emerge as an aftermath of the central bank's attempt to escape from the liquidity trap.

Proponents of all of the above-mentioned concepts present some persuasive empirical evidence supporting the proposed ideas. It seems, however, that in practice many of them might be difficult to tell apart due to identification problems. Moreover, since these are not competing but rather complementary ideas, there are probably many different sources of nonlinearities and state-dependency of the Taylor rule at play at the same time. The next paragraph looks over the results of papers where a nonlinear or state-dependent version of the Taylor rule was estimated, which should help to capture the overall shape of the Taylor rule.

2.4.3 Empirical evidence on nonlinearity and state-dependence of the Taylor rule

Although there are quite a few papers in which the nonlinear or state-dependent version of the Taylor rule is estimated, its overall shape seems to be difficult to deduce. The survey presented in Table A1.4 in Appendix A.1 shows that the evidence for nonlinearity and state-dependency of the Taylor rule is rather mixed and sometimes contradictory with respect to both periods in which nonlinearity and state-dependency were detected and to their particular shapes.

Among the sixteen overviewed papers, two studies (Castro 2011; Dolado, Maria-Dolores and Naveira 2005) found no evidence for nonlinearities in the Taylor rule throughout all of the analysed samples; another three papers (Kim, Osborn and Sensier 2005; Koo, Paya and Peel 2010; Surico 2007) detected nonlinearities before 1979 but no later; while two other papers (Dolado, Maria-Dolores and Murcia 2004; Petersen 2007) quite surprisingly discovered nonlinearities only after 1983 or 1985 but not before. However, since nonlinear models and nonlinearity tests always verify only a particular class of nonlinear shapes against linearity, and just one contradictory example is sufficient to break the general statement, one should not treat *no evidence* of nonlinearity as *evidence of* linearity. Therefore, following the results of the other nine surveyed studies, we claim that nonlinearity and state-dependency of the Taylor rule find strong empirical support.

As far as particular shapes of nonlinearity and state-dependency are concerned, it seems that individual findings are difficult to generalise. Apart from the aforementioned papers, also other studies (Cukierman and Muscatelli 2008; Lee and Son 2013; Kim and Nelson 2007) suggested that the estimates of the Taylor rule are not time and structural invariant and that the Taylor rule looks very different under different Federal Reserve presidencies. The pre-Volcker Taylor rule tends to be classified as either linear (Dolado, Maria-Dolores and Murcia 2004; Petersen 2007) or concave with respect to inflation or the output gap (Cukierman and Muscatelli 2008; Surico 2007); however, Koo, Paya and Peel (2010) found that it was convex with respect to inflation but concave with respect to the output gap. Evidence for the Volcker-Greenspan era is even more mixed, probably because Volcker and Greenspan should not be analysed together, as was pointed out by Cukierman and Muscatelli (2008) and Kim and Nelson (2006). In particular, the external conditions were quite different in both periods and it might be difficult to compare and aggregate the period of tough disinflation during Volcker's tenure and the period of keeping the inflation low under Greenspan. When treated separately, Volcker's reaction function seems to be linear with respect to the output and inflation gaps, while Greenspan's seems to be linear with respect to the inflation gap but concave with respect to the output gap (Cukierman and Muscatelli 2008). However, Florio (2006) showed that in both cases the reaction functions are dependent on the stance of the monetary policy, and Volcker was probably more cautious in lowering than raising interest rates, whereas Greenspan – just the opposite.

In summary, the survey presented here allows to claim that the nonlinearity and state-dependency of the Taylor rule are strongly supported by the data but, on the other hand, their particular shapes crucially depend on the analysed (sub)samples and tenures.

2.5 Monetary transmission mechanism as a system

The previous subsections presented both theoretical and empirical evidence for the nonlinearity and state-dependency of the three equations typically constituting a small model of the monetary transmission mechanism. Clearly, different sources of nonlinearity and state-dependency may interact, and thus dump or strengthen one another. The aim of this short subsection is to look over the results of studies in which the monetary transmission mechanism was estimated as a system allowing for its nonlinearity or state-dependency.

The contemporaneous New Keynesian models are very often based on some of the ideas and premises described in the previous subsections. However, usually only one or two particular sources of nonlinearity and state-dependency are considered at once. Moreover, due to log-linearising equations around the steady-state, it is not usually explicitly visible that the underlying relations are nonlinear.[29] Since we are not interested in the consequences of one or two particular sources of nonlinearity or state-dependency, but rather in some general and empirical patterns of asymmetries in impulse responses which are visible in the data, we turn our attention only to empirical papers. After all, the scope of this study is rather empirical than theoretical.

The survey presented in Table A1.5 in Appendix A.1 leaves no doubt that asymmetries are existent in the monetary transmission mechanism. Alessandrini (2003), Balke (2002) and Zheng (2013) found that the effects of the monetary policy are particularly pronounced when financial or credit conditions in the economy are stretched; while Hoppner, Melzer and Neumann (2005) detected a similar regularity if the economy is in a recession. Zheng (2013) also discovered that during financial distress the output-inflation trade-off worsens. On the other hand, Weise (1999) found that an unusual pattern emerges when output growth is already high or inflation is rising. Then the impact of the monetary policy on inflation is higher than otherwise, while the output effects are large but have an opposite sign. In other words, it seems that at economic peaks the restrictive monetary policy is potent to ‘kill two birds (a hawk and a dove) with one stone’, i.e. negative shocks both curb inflation and have positive output effects. Some other asymmetries with respect to high and low inflation regimes are also provided by Mandler (2010). In particular, he found a stronger reaction of the output growth to the federal funds rate shock and the inflation shock in the high inflation

[29] Naturally, when nonlinearities or asymmetries are points of interest, approximations of higher orders are used.

regime. By contrast, he also discovered stronger reactions of the inflation and federal funds rate to the federal funds rate shock and output growth shock in the low inflation regime.

As far as the size and sign asymmetries are concerned, the empirical evidence is mixed. Weise (1999) and Zhang (2013) held that larger monetary policy shocks have a larger unit impact than smaller ones, while Mandler (2010) claimed that the difference is negligible. Similarly, Balke (2002) and Angrist, Jordà and Kuersteiner (2013) pointed to the stronger effects of restrictive than expansionary monetary policy shocks, while Weise (1999) found at best mild such evidence and only for large shocks. At the same time, Chang and Jansen (2005) uncovered very temporary asymmetry with respect to large negative monetary shocks which delivers an upside-down impulse response for a short period of time.

Finally, Hoppner, Melzer and Neumann (2005) found that responsiveness of the economy, especially economic activity, to monetary policy shocks steadily decreases in time. This trend may be attributed to increasing efficiency of the regular component of the monetary policy (e.g. due to commitment and credibility) or to the changing structure of the economy (e.g. development of financial markets). This issue will also be discussed in the next section, which is devoted to the sources of asymmetries specific to the Greenspan era.

2.6 Summary

At the very beginning of this section we introduced the formal definitions of nonlinearity, state-dependency and asymmetry, and we presented the concept of the generalised impulse response function. In the following subsections we looked over the existing literature regarding nonlinearity and state-dependency of the Phillips curve, the IS curve, the Taylor rule and asymmetries in the monetary transmission mechanism as a system. The overview provided rich evidence that the monetary transmission mechanism exhibits significant nonlinearity and state-dependency at individual equation levels and asymmetries in impulse responses at the system level. The results were particularly sound and explicit in the case of the Phillips curve, the Taylor rule and the monetary transmission mechanisms as a system, while the evidence for the IS curve was rather indirect and speculative. The scope of this section was rather general, without referring to any specific individual periods in the U.S. economic history. In the next section, we turn our attention particularly to the Greenspan era and look over the literature on potential sources of nonlinearity and state-dependency of the monetary transmission mechanism and asymmetries in impulse responses which are exceptional for this period.

3. Premises behind nonlinearity and state-dependency of the monetary transmission mechanism specific to the Greenspan era

3.1 Introduction

In the previous section we focused on the general premises standing behind nonlinearity and state-dependency of the monetary transmission mechanism. As has already been mentioned, herein we put emphasis on potential sources of nonlinearity and state-dependency which are distinctive (if not endemic) of the Greenspan era. We start by discussing the phenomenon of the Great Moderation which accompanied Greenspan during his years as chairman of the Federal Reserve and which reshaped some stylised facts regarding business cycle properties and some basic economic relationships. In particular, we turn our attention to globalisation and structural changes in the U.S. economy, which are usually treated either as potential explanations or constituents of the Great Moderation, and their possible implications for the monetary transmission mechanism. Next, we also consider the financial crises and market distresses which were abundant in the Greenspan era and might have exerted some influence on the monetary transmission mechanism at that time. Finally, we focus on the 'Greenspan standard', i.e. the way Greenspan conducted the monetary policy. As previously, we try to uncover some peculiarities which may signal nonlinearity and state-dependency of the monetary transmission mechanism resulting in asymmetric impulse responses in that period.

3.2 The Great Moderation

At the turn of the century, economists were riveted by finding a large decline in the volatility of many macroeconomic time series. Kim and Nelson (1999) and McConnell and Perez-Quiros (2000) independently identified a significant drop in volatility of GDP growth in the middle of the 1980s, while Blanchard and Simon (2001) perceived it as a continuation of the post-war stabilisation trend which was only interrupted in the 1970s and early 1980s. Similarly, Romer (1999) and Gordon (1998) noticed that in the late 1980s and 1990s, robust economic growth was also accompanied by low and stable inflation, which induced Gordon to label the phenomenon a *goldilocks economy* – an economy which is neither too hot to boost inflation nor too cold to cause a recession but 'just right'. Finally, an elaborate study by Stock and Watson (2003) confirmed a similar pattern of lowered volatility for many other U.S. economic time series and they coined the term *the Great Moderation*.

As was pointed out by Gordon (1998), such behaviour of the economy struck the macroeconomists as being a thoughtful puzzle since historical experience showed that increasing economic activity and lowering unemployment should cause inflation pressure. Thus, the Great Moderation called into question the concepts of the Phillips curve and the non-accelerating inflation rate of unemployment or potential output which, after all, are still cornerstones of the monetary policy framework. Many authors suggested that the Great Moderation coincided with smaller and possibly less persistent, or less volatile with respect to the impulse response time-horizon, effects of monetary policy shocks (see e.g. Barth and Ramey 2002; Boivin and Giannoni 2002, 2006; Boivin, Kiley and Mishkin 2010), and lowered the predictive power of the federal funds rate as a leading indicator of economic activity (e.g. Gertler and Lown 2000). Intuitively, the monetary transmission mechanism was not an exception, and widespread structural instabilities in estimates and forecast performances were also documented with respect to many basic macroeconomic relationships (see Stock and Watson 1996, 1999).

Although the Great Moderation is a well-documented phenomenon, it is difficult to date it precisely. The problem of setting its starting point[30] shows, however, that the onset of the Great Moderation was rather a more prolonged process than just a sudden switch into a new regime. By the same token, although it might be very tempting, a study by Clark (2009) indicated that at least in 2009 it was too early to announce that 'the Great Moderation is over'. If the Great Moderation is at least partially indeed a process of transition from an 'old' to a 'new' regime, the detected structural instabilities in many basic macroeconomic relationships are not just one-off structural breaks but rather some structural changes evolving in time. In particular, this means that the monetary transmission mechanism under Greenspan was not only different when compared to the Volcker or pre-Volcker era, but it could also vary between the beginning (11 August 1987) and the end (31 January 2006) of the Greenspan era. Thus the Great Moderation might be a potential source of nonlinearity and state-dependency of the monetary transmission mechanism in the Greenspan era and it is worth discussing the Great Moderation in that context.

Among many there have been five main 'keyword' (and partially interdependent) explanations of the phenomenon of the Great Moderation:

[30] Stock and Watson (2003) showed that estimated breakpoints in conditional variance and conditional mean vary for selected time series but usually occurred between the early 1980s to early 1990s.

- globalisation
- structural changes in the U.S. economy
- international crises
- better monetary policy
- good luck.

In the next subsections we shortly discuss all of the presented explanations of the Great Moderation apart from the ‘good luck’ hypothesis, which either leaves little to discuss and interpret from the perspective of our research agenda or is a self-critical manifestation, that economists are not able to explain the Great Moderation with their models[31]. Bearing in mind the scope of this study, we abstract from assessing the relative importance of the proposed explanations but rather focus on their implications in the context of potential nonlinearities and state-dependency of the monetary transmission mechanism. Thus we use the proposed theories justifying the Great Moderation to organise our discussion on nonlinearity and state-dependency of the monetary transmission mechanism in the Greenspan era. Such a disaggregated approach allows us to be more precise regarding the direct sources of nonlinearity and state-dependency with respect to particular equations and coefficients, especially in the case of ‘globalisation’ and ‘structural changes in the U.S. economy’ explanations. Moreover, when discussing the role of international crises we also take the opportunity to consider a more general and possible impact of the crises and market distresses which were abundant in the Greenspan era on the potential nonlinearity and state-dependency of the monetary transmission mechanism. Similarly, the ‘better monetary policy’ hypothesis is convenient to discuss the monetary policy under the Greenspan presidency and to seek elements of the ‘Greenspan standard’ which may suggest nonlinearity and state-dependency of his behaviour as a Federal Reserve chairman.

3.3 Globalisation

The Greenspan era coincided with a period of vigorous globalisation. Though it is not the aim of this study to create an extensive list of milestones of globalisation, it is worth considering just a few of the ‘big events’ from between 1987 and 2006 which give a flavour of the huge changes that took place during those 20 years:

[31] See Giannone, Lenza and Reichlin (2008) for an interesting discussion on how small models confuse ‘good luck’ with ‘ignorance’ in the context of the Great Moderation.

- 1989 – the Fall of Communism in Central and Eastern Europe; Asia-Pacific Economic Cooperation is established
- 1990 – the Shanghai Stock Exchange is re-established
- 1991 – the World Wide Web opens up to the public; the Soviet Union is dissolved
- 1994 – the North American Free Trade Agreement comes into force
- 1995 – the World Trade Organisation is formed
- 1998 – Google is founded
- 1999 – the 'Battle of Seattle' ('N30') takes place
- 2001 – September 11
- 2004 – Facebook is founded

According to the International Monetary Fund (2000), from an economic point of view there are four main aspects of globalisation: trade, movement of people, capital movements, and spread of knowledge and technology. The literature suggests that the first three factors are theoretically potent to deliver significant nonlinearity and state-dependency of the Phillips curve, while the last two – of the IS curve.

3.3.1 Impact of globalisation on the Phillips curve

Not surprisingly, the focal point of many studies was directed at the Phillips curve and globalisation as a source of low and stable inflation accompanying robust economic growth. There are two main strands of literature: one strand is focused on the issues of openness (the direct effect of globalisation which needs an open economy framework), while the other strand is focused on increased competition (the indirect effect of globalisation which may be analysed in a closed economy framework). In each case two views are presented which give, in some manner, opposite predictions on the impact of globalisation on the slope of the Phillips curve.

(1) Early papers by Romer (1993) and Lane (1997) suggested that an economy's increased trade openness should reduce incentives for central bankers to conduct an expansionary monetary policy via steepening the Phillips curve and thus lowering the sacrifice (or gain) ratio. The explanation is quite straightforward – since a positive monetary shock leads to real exchange rate depreciation, it also raises import prices which have larger weights in both the producer and consumer price indexes if an economy is more open. Therefore, the more open

an economy is to trade, a positive monetary shock is translated to a larger extent into prices rather than output. Bearing in mind the time inconsistency problem and the inflation bias in the spirit of the Kydland-Prescott Barro-Gordon model (Kydland and Prescott 1977, Barro and Gordon 1983), it should result in a lower inflation rate than in the case of a closed economy.

On the other hand, Daniels and VanHoose (2006) showed that the results crucially depend on market structure, and if one allows for monopolistic competition and incomplete wage rigidity in the New Keynesian style, larger trade openness reduces the pricing power of domestic firms and thus flattens the Phillips curve. A lower inflation rate arises because the reduced pricing power of domestic firms also restrains the responsiveness of firms to a given monetary shock, and despite a larger sacrifice (or gain) ratio both the output and inflation effects of monetary shocks decrease in trade openness. Such a relation should hamper incentives to conduct a discretionary monetary policy aimed at boosting output and therefore reduces inflation and lowers the inflation rate.

Binyamini and Razin (2008) extended the New Keynesian model with goods and capital mobility as was derived by Razin and Loungani (2007) and provided a more integrated approach to show that increased mobility of goods, capital and labour, both individually and taken together, flatten the Phillips curve. The intuition behind such a result is that all channels of openness allow domestic households to be more independent from domestic firms and vice versa, which weakens the responsiveness of inflation to domestic demand shocks. They also found that if the monetary authorities want to conduct a welfare-based policy they should respond more aggressively to inflation fluctuations but less aggressively to output fluctuations when compared with a closed economy. Therefore, central bankers have fewer incentives to create an inflation bias, which should eventually result in a lower inflation rate.

Borio and Filardo (2007) presented an anecdotal rationale for decreased sensitivity of the Phillips curve to the domestic output gap and increased sensitivity to the global output gap due to broadly defined openness. The intuition is that in a globalised world, country-specific demand shortages can easily be offset by global excess demand, thus firms should pay some attention to global slack, not only to domestic slack. In consequence, the slope of the Phillips curve should decrease with respect to the domestic output gap, and the global output gap should enter the equation as a new variable.

(2) Rogoff (2003, 2006) claimed that increased competition, which is one of the most important consequences of globalisation, steepens the Phillips curve since it creates an environment of more flexible prices and wages. Analogously, as in works by Romer (1993) and Lane (1997), a steeper Phillips curve should lead to both a lower inflation bias and inflation rate than in a closed economy.

On the other hand, Sbordone (2010) focused on the impact of increased competition on the slope of the Phillips curve *via* an increased number of goods traded. She departed from a typical assumption of constant demand elasticity but made it dependent on the relative market share of differentiated goods. The final outcome was ambiguous – the analysed channel is potent to deliver both a steeper and flatter Phillips curve depending on the shape of the demand curve, however, flattening the Phillips curve seems to be a more plausible scenario.

There is vast empirical evidence documenting that the U.S. Phillips curve flattened in the Great Moderation when compared to previous years (e.g. Roberts 2006; Boivin and Giannoni 2006; Borio and Filardo 2007; Mishkin 2007; Tetlow and Ironside 2007), but there is little robust support for the global output gap hypothesis as was suggested by Borio and Filardo (2007). In particular, Ihrig et al. (2007) showed that estimates are usually insignificant or wrongly signed and are not robust with respect to the specification of global slack, while Ball (2006) claimed that 'foreign gaps are at most a secondary influence on inflation'. Moreover, Woodford (2010) provided considerations which pointed to the fact that such an influence lacks a solid theoretical background.

Therefore, the results are consistent with the predictions of Daniels and VanHoose (2006) and Binyamini and Razin (2008); potentially consistent with Sbordone (2010), but at odds with Romer (1993), Lane (1997), Borio and Filardo (2007), and Rogoff (2003, 2006).[32] On the other hand, Sbordone (2010) claimed that although 'for large enough increases in the number of goods traded, the slope of the Phillips curve is in general declining', the empirical patterns in the U.S. trade are rather too small to create such an effect. Therefore, it seems that it is globalisation *via* its openness channel, which is at least partially responsible for the flattening of the Phillips curve. Indeed, when independence of the central bank is controlled for, there exists a significant and positive correlation between the openness and sacrifice ratio in cross-

[32] Alternatively, there may be many effects at play at the same time and the openness effects described by Daniels and VanHoose (2006) and Binyamini and Razin (2008) turned out to be stronger than those proposed by Romer (1993) and Lane (1997).

country data (e.g. Daniels, Nourzad, VanHoose 2005; Badinger 2008). Nevertheless, Milani (2010) and Kuttner and Robinson (2010) found this effect to be rather small.

It should be noted, however, that the above-mentioned findings do not imply that globalisation, or more precisely the openness channel, is responsible for low inflation. Evidence for the negative correlation between openness and the level of inflation is rather mixed. While there is little doubt that such a relation may hold for developing countries, it does not seem to be valid for developed countries (e.g. Romer 1993; Badinger 2008). One of the usually proposed explanations is that developed economies have already institutionally overcome the time-inconsistency problem, and intuition based on the Kydland-Prescott Barro-Gordon model is no longer an appropriate one to be used in that context.[33] As was pointed out by Kohn (2006), no structural changes 'relieve central banks of their responsibility for maintaining price and economic stability' and 'in a world of separate currencies that can fluctuate against each other over time, each country's central bank determines its inflation rate'.

3.3.2 Impact of globalisation on the IS curve

As opposed to the case of the Phillips curve, the literature on the impact of globalisation on the IS curve is very scarce. As far as we know, there are only two general premises as were suggested by Woodford (2010) which potentially allow globalisation to influence the shape of the IS curve and were considered in the literature. However, neither of them seems to be relevant in the case of the U.S. economy.

(1) Woodford (2010) analysed the impact of globalisation on the link between monetary policy actions and the market nominal interest rate. Although technically these considerations refer to the LM curve, we can treat them as analysing the wedge which may arise between the interest rate in the Taylor rule (the central bank's official interest rate) and the IS curve (the market nominal interest rate).[34] The intuition behind this is quite straightforward – in a world of free capital flows and common standards the market interest rate can be driven by 'global

[33] We turn back to the issue later when we discuss a 'better monetary policy' explanation and the 'Greenspan standard'.

[34] This discrepancy arises because in standard models it is usually assumed that the central bank is able to control the domestic short-term nominal rate (the Taylor rule is equivalent to the LM curve), while the essence of Woodford's considerations is to try to relax this assumption. Conversely, this point may also be treated as a source of potential nonlinearity or state-dependency of the Taylor rule.

liquidity' rather than by 'domestic liquidity' because a central bank may lose its monopoly power to supply 'base money'. However, referring to the canonical model by Clarida, Galí and Gertler (2002), Woodford (2010) showed that any policy aim may be equivalently achieved either with the use of an interest rate or a monetary base. Although their paths in different countries can be interrelated, there is no special role for global liquidity. Moreover, such a result holds even if one allows for imperfect substitution between currencies as means of payments within the border.

Similarly, Kamin (2010) claimed that despite common global factors affecting individual economies and increased co-movements of their interest rates, a central bank does not lose control over short-term market interest rates if floating of the currency is allowed. Nevertheless, international coordination of the monetary policy may be helpful with respect to liquidity provision arrangements (Kamin 2010) and global risk management (Rogoff 2006).

(2) By the same token, Woodford (2010) also analysed the hypothesis of increased responsiveness of domestic activity (output gap) to the global interest rate rather than the domestic one. The result is parallel – although the IS curves in different countries can be interrelated and real interest rates can be tied in equilibrium, there is no special role for the global interest rate in the IS equations.

In both cases, apart from the theoretical justification as was provided by Woodford (2010), one may obviously argue that such considerations seem to be futile for the U.S. economy. Bearing in mind its relative size and the predominant role of the U.S. dollar as a reserve currency, the U.S. economy drives, rather than is driven by, global liquidity and the global interest rate. Indeed, an empirical study by Milani (2010) showed that the standard version of the IS curve fits the data better than when its parameters are allowed to vary with trade openness. In the latter case the changes caused by globalisation seem to be moderate.

3.3.3 Impact of globalisation on the Taylor rule

It has already been discussed in the previous chapter that nonlinearity and state-dependency of the Taylor rule may arise as a result of nonlinearity and state-dependency of the model of the economy or relaxation of some specific assumptions underlying the derivation of the optimal policy function. In that respect there is no special role for globalisation as a direct source of nonlinearity and state-dependency of the Taylor rule. There are, however, at least three channels through which globalisation may exert some influence on the shape of the Taylor rule.

(1) When considering the impact of openness on the shape of the Phillips curve, we have already mentioned that according to the model by Binyamini and Razin (2008), a welfare-based monetary policy should put greater emphasis on inflation and smaller emphasis on the output gap than when compared with a closed economy. By the same token, Devereux and Sutherland (2010) claimed that financial globalisation even strengthens price stability as the most important aim of central banks since it also elevates international risk-sharing.

(2) Wagner (2002) noticed that globalisation increases uncertainty regarding parameters in the economic models and the information content of the inflation and output gap. Giannoni (2002) showed that allowing for uncertainty in both the Phillips curve and the IS curve should induce a central bank to act more aggressively in response to changes in the inflation and output gap, respectively. Similarly, Onatski and Stock (2002) claimed that policy rules which are robust to uncertainty usually predict a stronger reaction than standard rules derived under a linear-quadratic framework. It should be noted, however, that the results depend on the exact formulation of uncertainty. Finally, as predicted by the already-discussed models by Meyer, Swanson and Wieland (2001), Swanson (2006) and Tillmann (2011), uncertainty may induce the monetary authorities to conduct a policy which is relatively irresponsive to small deviations from the desired level but highly reactive if actual values of inflation or the output gap are far from their targets.

(3) In most standard models, openness of the economy does not call for any special need to incorporate additional or different variables in the Taylor rule. As was discussed by Rogoff (2006), if both inflation and the output gap are taken into account in the Taylor rule the benefit from including either an exchange rate or the terms of trade is insignificant because their role is already (indirectly) captured by the two standard variables. Nevertheless, there are some exceptions which on theoretical grounds may require to modify the Taylor rule if the monetary policy rule should be optimal. Smets and Wouters (2002) showed that there is an independent role for exchange rate stabilisation if the exchange-rate pass-through into import prices is imperfect or gradual. A similar outcome arises if one allows for a home bias in consumption (Faia and Monacelli 2008). Rogoff (2006) noticed, however, that such models usually assume that the exchange rate is tightly tied to fundamentals and contains additional

information on the state of the economy, while in practice large volatility of the exchange rate may cause a severe signal extraction problem. He claimed that arguments against including the exchange rate in the Taylor rule are quite similar to those against including asset prices as put forth by Bernanke and Gertler (1999).

On the other hand, Ball (2002) claimed that openness of the economy may require more serious modifications in the monetary policy strategy; for example, according to his proposition, greater macroeconomic stability would be ensured if the monetary authorities targeted long-run inflation, which would smooth out variations due to exchange rate fluctuations instead of the actual inflation. Conversely, Taylor (2008) assessed the standard policy framework as sufficient and did not see any particular need to modify it. He found that even gains from international coordination of interest rate policies (coordination in the narrow sense) are very small.

3.3.4 Impact of globalisation on the monetary transmission mechanism as a system

To some extent, a study by Boivin and Giannoni (2010) may serve as an empirical summary of the impact of globalisation on the monetary transmission mechanism. They found that international or global factors play an important role in explaining the fluctuations of the U.S. macroeconomic indicators, although it is difficult to notice a general pattern in that they became more important over the period of 1984-2005. In some cases (e.g. long-term interest rates, import and export prices), however, this is true. Similarly, there is little evidence that globalisation has left its stamp on impulse response functions in the monetary transmission mechanism and its impact seems to be limited to reducing persistence in the impulse responses. The results suggest that even if globalisation reshaped some of the equations constituting the monetary transmission mechanism, little has changed in the monetary transmission mechanism as a system due to globalisation.

3.4 Structural changes in the U.S. economy

It is widely recognised that the Greenspan era was also an era of intense structural changes in the U.S. economy and of rapid development of information technology and financial services and innovations[35] (see e.g. Gordon 1998, Temple 2002). Although there is vast literature discussing these as potential explanations of the phenomenon of the Great Moderation, much less is known about their precise impact on the monetary transmission mechanism and its equations. The problem arises probably because there are quite many channels through which structural changes in the U.S. economy may influence the shape of the monetary transmission mechanism, and their effects are often contrary. As previously, we discuss these channels with respect to the Phillips curve, the IS curve and the Taylor rule.

3.4.1 Impact of structural changes in the U.S. economy on the Phillips curve

Although the literature on the possible impact of structural changes in the U.S. economy on the Phillips curve is not very abundant, the existing studies allow to discuss as many as eight premises which justify the nonlinearity and state-dependency of the Phillips curve due to these changes.

(1) It is often argued that the development of information technology lowers menu and managerial costs related to price changes and thus allows for more frequent price adjustments (e.g. Willis 2003), which should result in a steeper Phillip curve. It goes without saying that introducing scanner technology and online price catalogues facilitates the process of changing prices when compared to labelling every single item and printing paper versions of price catalogues. Similarly, improvements in hardware and software make gathering and processing of information much easier than in the 'paper era', and thus allows managers to make more frequent and adequate price adjustments. Willis (2003) provided some evidence that the Great Moderation indeed corresponds with more frequent price adjustments than the previous period.

(2) By the same token, Willis (2003) noticed that information technology allows consumers to compare prices much more easily (e.g. printed vs online catalogues). Although he referred to this argument only with respect to lowering the cost of antagonising customers by changing prices, more transparent prices should also lead to a more competitive market and the lower pricing power of firms. In every case, it should result in a steepening of the Phillips curve.

[35] We purposefully avoid using the term 'new economy' since it seems to be very imprecisely referred to in the literature and may be ambiguous.

(3) Cecchetti (2006) held that 'technology has been used to make production more responsive to changes in product demand, thereby reducing the level of inventories'. If the suggested causal effect is true and a reduced level of inventories to shipments is indeed an indicator of production being more demand elastic, there is no doubt that the slope of the Phillips curve should flatten. Otherwise[36], it is worth noticing that a lower inventory-to-shipment ratio increases the risk of stock-outs in the presence of which firms tend to raise prices rather than output. Therefore, we argue that the overall effect is somewhat ambiguous, especially for large positive demand shocks.

(4) As was pointed out by Willis (2003) and Cecchetti (2006), important structural changes also took place in the labour market. In particular, an increased share of temporary workers allows firms to adjust the level of the workforce and production more easily in periods of expansions and recessions, thereby smoothing out inflationary and deflationary pressures, respectively. In consequence, the Phillips curve should be more flat.

(5) Berk (2002) pointed out that technology development gives rise to goods which can be represented in digital form and are subject to increased returns to scale on the supply side and network effects on the demand side. Such an environment clearly favours natural monopolies and a 'market structure characterised by a small number of large price-setting entities'. As was already discussed in paragraph 1.2.2, this implies a concavity of the Phillips curve, thus development of information technology may be responsible for changing the curvature of the Phillips curve into a more concave shape.

(6) Berk (2002) also claimed that the development of information technology should result in an easier signal extraction problem, in the spirit of Lucas (1972, 1973), due to lower costs of gathering and processing information. Then the Phillips curve should be steeper. We argue, however, that the signal extraction problem in a real-time setting under structural changes in the economy might be even more difficult to solve despite better 'tools'. The latter view is supported by Campbell (2007), who showed that the Great Moderation was characterised by lower macroeconomic predictability than in previous years. Thus, the overall outcome of changes in the severity of the signal extraction problem on the slope of the Phillips curve might be opposite to that suggested by Berk (2002).

[36] A lower inventory-to-shipment ratio may be the result of, e.g. engaging computers in the process of inventories management independently of making production more flexible with respect to demand.

(7) The above-mentioned point may also be extended to the formulation of inflation expectations. On the one hand, easier access to information and publicly available forecasts should make inflation expectations more forward-looking yet, on the other hand, ongoing structural changes in the economy can make a forecast less accurate and more backward-looking in reality. The outcome of the two effects is ambiguous, but the given suggestion justifies the possibility of a state-dependent Phillips curve in which the development of information technology influences the balance between the backward- and forward-looking components of inflation expectations. An empirical assessment of the proposed channels can be, however, difficult to conduct due to corresponding changes in the credibility and communication strategy by the Federal Reserve.

(8) It is worth pointing out that structural changes in the U.S. economy also have the composition dimension. If the sectoral Phillips curves for manufacturing and low-tech sectors differ substantially from the sectoral Phillips curves for services and high-tech sectors, the aggregate Phillips curve may evolve in line with the evolution of the economy's structure. A study by Nakamura and Steinsson (2008) revealed that services and high-tech sectors tend to adjust prices less frequently than the manufacturing and low-tech sectors. Thus, as the share of the latter sectors becomes smaller (see e.g. Alcala and Sancho 2004; Moro 2012), the slope of the Phillips curve should decrease.

The presented overview gives no clear-cut predictions of the impact of structural changes in the U.S. economy on the Phillips curve (see Table A2.1 in Appendix A.2 for a summary table). As was discussed in paragraph 2.4.1, there have been many studies documenting a flattening of the Phillips curve during the Great Moderation, and only partially could this be justified by globalisation. Thus, one may expect that the balance of the considered premises is directed towards a flattening of the Phillips curve rather than its steepening.

3.4.2 Impact of structural changes in the U.S. economy on the IS curve

Similarly as in the case of the Phillips curve, the number of papers analysing the impact of structural changes in the U.S. economy on the shape of the IS curve is scarce. Nevertheless, the found studies allow to distinguish as many as seven possible channels through which the shape of the IS curve may be affected by structural changes in the U.S. economy (see Table A2.2 in Appendix A.2 for a summary table).

(1) Berk (2002), Cecchetti (2006) and Woodford (2000) considered the consequences of the possible erosion of a central bank's monopoly position as a supplier of means of payment (e.g. due to the development of various forms of 'e-money' issued by the private sector) and a provider of settlement and balance services (e.g. due to computer systems run by the private sector). They argued that although such changes require an important strategic and operational modification of the monetary policy framework, the central bank should not lose control over the short-term interest rate and the monetary policy should continue to be effective even under the most extreme scenarios. On the other hand, we argue that modifications in the policy framework are usually introduced in response to rather than before such challenges appear. Thus, it is possible that the development of financial innovations of this kind may at least temporarily impair the interest rate pass-through or make it more sluggish. Then the slope of the IS curve may flatten and/or the impact of the short-term interest rate may be more prolonged in time.

(2) Berk (2002), Cecchetti (2006) and Willis (2003) argued that the development of financial innovations may result in dampening the credit channel of the monetary policy. In particular, the evolution of capital markets and various financial instruments reduces the external financing premium and makes enterprises and consumers less dependent on bank credit. Cecchetti (2006) claimed that 'innovations in finance have helped to assure that companies and consumers have access to resources even when times are tough'. As was pointed out by Berk (2002), the effect might be strengthened by the development of information technology, which should reduce the problem of asymmetric information and even further lower the external finance premium. Therefore, the evolution of information technology combined with financial innovations should lead to a gradual weakening of the inverse relation between the slope of the IS curve and credit conditions in the economy.

(3) Financial innovations and the development of hedging instruments facilitate the intertemporal substitution of income and cash flows which 'should work against the substitution effect of monetary transmission' (Berk 2002). Intuitively, better hedging instruments allow to 'freeze' the interest rate and separate consumption and investment decisions from the current interest rate and thus make them relatively more dependent on the expected income, net worth and cash flows. Then the IS curve should be flatter and more forward-looking. However, we argue that this microeconomic perspective might be somewhat confusing. It is worth noting that from the macroeconomic point of view the interest rate risk

does not magically disappear but is only transferred from economic agents with higher relative risk aversion or lower elasticity of intertemporal substitution to economic agents with lower relative risk aversion or higher elasticity of intertemporal substitution. The overall effect clearly depends on the distribution of consumption and investment among the counterparties.

On the other hand, we agree that the IS curve might be more forward-looking, but rather due to increased possibilities of smoothing consumption and investment as a result of broader access to financing. Then the past and current income, net worth and cash flows should truly play a relatively smaller role in determining consumption and investment.

(4) The above-mentioned effect could also be potentially strengthened by information technology allowing for better access to information and forecasts but, as we have already discussed in the case of the Phillips curve, the ongoing structural changes make forecasting even more difficult despite the better ‘tools’.

(5) Berk (2002) noticed that financial innovation may influence the income effect of the monetary policy again due to increased possibility of hedging against changes in the interest rate. It is probable that borrowers and risk hedgers have higher propensity to consumption and investment than depositors/lenders and risk holders, respectively (see e.g. Vrolijk 1997). Then the possibility of hedging should reduce the negative income effects of the monetary policy and make the IS curve flatter. Nevertheless, we claim that this effect can be easily outweighed by the positive impact of financial development on the size of the credit and debt market. Jerman and Quadrini (2006) documented that outstanding debt to the GDP ratio increased from 63% in 1984 to 82% in 2005 and witnessed large swings during that period. Then the income effects of the monetary policy in 2005 should be even more profound than they were in 1984 and thus the IS curve should be steeper.

(6) Berk (2002) used similar argument as before to justify that also the wealth effects of the monetary policy might be reduced due to increased possibility of hedging against changes in the interest rate. And again we claim that this effect might be simply outbalanced by the positive impact of financial development on the size of the capital and real estate market (see e.g. Temple 2002 and Grydaki and Bezemer 2013). Therefore, we find another argument for a steepening rather than a flattening of the IS curve.

(7) Similarly as in the case of the Phillips curve, one may expect that structural changes in the U.S. economy influence the aggregate IS curve also through composition effects. According to the credit view of the monetary policy, investment of young and risky 'new economy' companies should be more reactive to the interest rate than investment of experienced and stable 'old economy' companies. By the same token, also investment of service firms with typically low levels of tangible assets should be more flexible with respect to the interest rate than investment of manufacturing firms with relatively high levels of potential collateral. Bearing in mind the increasing shares of 'new economy' firms, the IS curve should become steeper.

Although to our knowledge there are no studies that directly focused on the problem of the changing slope of the IS curve, the hypothesis of a steeper IS curve finds some empirical support. Simple algebra on the estimates of the DSGE model by Boivin, Kiley and Mishkin (2010) reveals that the slope of the IS curve for the consumption equation is indeed much steeper for the period 1984Q1-2008Q4 than for the period 1966Q1-1979Q3. A similar conclusion may be reached in Boivin and Giannoni (2006) when comparing the estimates for 1979Q3-2002Q2 and 1959Q1-1979Q2, though the difference is much smaller.

At the same time, our intuition that financial development leads to a steeper IS curve is supported by the already mentioned study by Stracca (2010). He found that the IS curve is steeper in countries with higher private credit to GDP, stock market capitalisation to GDP and households to GDP ratios. Similarly, Hahn (2003) claimed that well-developed financial systems magnify monetary shocks, which is also consistent with the steeper IS curve. The results obtained by Stracca (2010) also revealed that the slope of the IS curve is steeper in (OECD) countries with a lower share of industry, which is consistent with the proposed 'composition hypothesis'. Therefore, we claim that it is highly probable that a steepening of the IS curve is at least partially caused by the structural changes in the U.S. economy which were discussed in that section.

3.4.3 Impact of structural changes in the U.S. economy on the Taylor rule

As was already discussed, most likely the structural changes in the U.S. economy lead to a flattening of the Phillips curve and a steepening of the IS curve. In such an environment the monetary authorities may be relatively more reluctant to raise interest rates since a restrictive monetary policy comes at a larger cost than before. We argue that these effects might be strengthened by uncertainty which – in contrast to the issues deliberated upon in paragraph 2.4.2 – should induce central bankers to act less aggressively. The reason for this supposed difference lies in a specific source of uncertainty in the context of structural changes in the U.S. economy.

Inoue (1998) pointed out that innovations in information technology cause cardinal measurement errors in economic statistics due to rapid changes in the quality of goods and services which are difficult to reflect in price indexes and thus may seriously distort both inflation and GDP statistics. The emergence of new goods and services also creates coverage problems. In consequence, official inflation can be overestimated while GDP growth can be underestimated. Moreover, Cechetti (2006) accentuated the difficulties in estimating potential growth when the productivity trend is changing and provided some empirical evidence for its consequential underestimating by professional forecasters. As he pointed out, 'during periods of transition, it is extremely difficult to distinguish permanent from transitory shifts in output growth, and adjust policy correctly.' Bearing in mind that the risk of overestimating inflation and underestimating GDP growth or the output gap is larger than for the opposite scenario, the monetary authorities should react less aggressively to deviations of both actual inflation and actual output from their targeted values. Perhaps central bankers should pay more attention to the first differences and variance rather than the levels of inflation and output.

Combining the two effects as described above (structural changes and uncertainty) suggests therefore that an optimal monetary policy should probably be more cautious when raising interest rates than before, since both the probability and costs of groundless tightening of the monetary policy are relatively large. In such an environment the 'wait and see' strategy might be more efficient than the pre-emptive one. On the other hand, however, easier access to information and ICT extends the possibilities and lowers the costs of economic and econometric research, which may induce central bankers to act more firmly and pre-emptively. Thus, the overall effect seems to be difficult to deduce.

3.4.4 Impact of structural changes in the U.S. economy on the monetary transmission mechanism as a system

The evidence presented here on the shifting slopes of the Phillips curve and the IS curve suggests that structural changes in the U.S. economy should lead to important changes in the monetary transmission mechanism as a system. Although, as was mentioned in subsection 2.5, such changes have indeed been detected, they, quite surprisingly in this context, point to smaller and less persistent or less volatile effects of monetary policy shocks with respect to both inflation and economic activity. Counterfactual analyses conducted by Boivin and Giannoni (2006), and Boivin, Kiley and Mishkin (2010), revealed that when changes in the monetary policy and their impact on expectations are taken into account, little room remains for the role of changes in the parameters governing the behaviour of the private sector. Clearly this does not mean that these effects are not important at all, but simply that they have been outweighed by shifts in the regular component of the monetary policy. Moreover, it is also possible that modifications in the monetary policy were partially caused by the development of information technology and financial innovations.

3.5 Crises and market distresses

3.5.1 International crises and the ‘global saving glut’

Gordon (1998) referred to international crises as one of the potential explanations of the Great Moderation. According to this reasoning the set of international crises ‘created a flight to quality and the American “safe haven” in world capital markets that has appreciated the dollar and reduced both interest rates and import prices in the United States’. Indeed, when we take a look at the list of important financial crises outside the United States it covers crises of different source and nature, and seems to be quite long:

- 1990 – Collapse of the Japanese stock exchange initiating Japan’s Lost Decade or even Lost Two Decades
- 1991-1993 – Scandinavian Crisis
- 1992 – Black Wednesday
- 1994-1995 – Mexican Crisis
- 1997-1998 – Asian Crisis
- 1998 – Russian Crisis
- 1999 – Brazilian Crisis
- 2001 – Turkish Crisis
- 2001-2002 – Argentinian Crisis.

Although the hypothesis of international crises as an explanation for the Great Moderation has not received too much attention, we argue that flight to quality in an international dimension combined with the 'global saving glut'[37] (Bernanke 2005) is potent to at least temporarily or occasionally affect the shape of the monetary transmission mechanism. In particular, we claim that in periods of great capital inflow to the U.S., possibly caused by international flight to quality, the Federal Reserve may lose its leverage over long-term interest rates with the use of the short-term rate.

On the one hand, Bernanke (2007) held that the Federal Reserve, even in the presence of the global saving glut, retains its leverage over long-term interest rates by setting a short-term interest rate (and shaping expectations). Conversely, Thornton (2012) claimed that the link between long-term rates and the Federal Reserve's short-term interest rate has been non-existent since the Federal Reserve adopted a short-term interest rate as its policy instrument. We argue that both positions seem to be too extreme. In contrast to Bernanke (2007), Thornton's (2012) estimates leave very little doubt that the Federal Reserve's impact on long-term rates experienced structural changes from a statistically significant and meaningful relation in 1985 to virtually no relation at all twenty years later. But, at the same time, Thornton's econometric approach focused on seeking only one, single structural break (he dated it as taking place in 1988), while the estimates he obtained and the tests he performed show that there was also at least one more structural break in 1994. Moreover, this is also when the estimates start to exhibit a significant trend, which questions whether the structural change was truly immediate or perhaps more prolonged in time. We claim that the time pattern of the estimates he found visually correlates with foreign flows into U.S. bonds as were calculated by Warnock and Warnock (2005). Apart from this, the year of the second possible structural break (i.e. 1994) is also the year when a series of crises began in developing countries.

To our knowledge there are no studies that analysed all of the proposed links together. However, the 'Greenspan conundrum' (Greenspan 2005), when despite raising the federal funds rate seventeen times by 25 basis points, from 1% to 5.25% in the period 2004-2006,

[37] Bernanke (2005) claimed that financial crises in developing countries moved their collective current account deficit to the collective current account surplus. In particular, East Asian countries transformed from being net importers to being net exporters and quickly started building up large foreign-exchange reserves. The effect was strengthened by similar behaviour by China, the oil exporters and the savings propensities of mainly Germany and Japan. A large part of the reserves was invested in the U.S. as a result of 'the development and adoption of new technologies and rising productivity in the United States together with the country's long-standing advantages such as low political risk, strong property rights, and a good regulatory environment'.

long-term rates were rather going down than up, may serve as an anecdotal example of a situation when the Federal Reserve seemed to have lost its leverage over long-term rates by using a short-term rate due to sudden foreign inflows on the bond market (Warnock and Warnock 2005; Craine and Martine 2009).[38]

In conclusion, we claim that the suggested hypothesis, i.e. that in periods of sudden capital inflow to the U.S., possibly caused by international flight to quality, the Federal Reserve's impact on long-term interest rates via the federal funds rate may be dampened, is plausible. Clearly, it should be treated as a working hypothesis and needs much more empirical investigation but at the same time it is also consistent with the general and already mentioned finding that the Great Moderation corresponds to smaller effects of the monetary policy.

3.5.2 Domestic crises and market distresses

Despite the coined name, the Great Moderation was not a period that was free from any domestic crises and market distresses. When we compare the average number of major stock-market volatility shocks as were identified by Bloom (2009), there is no difference between the pre-Greenspan period and the Greenspan era – in both cases major stock-market volatility shocks happen once every 2.75 years, on average. Moreover, it was the Greenspan era when four of the largest shocks took place if we consider the years 1962-2006.[39] Again, the list of domestic crises and periods of market distresses is quite long (* denotes episodes which were identified as major stock-market volatility shocks on the U.S. market by Bloom (2009)):

∗ 1987 – Black Monday
• 1989 – Federal Savings and Loan Insurance Corporation is abolished (Savings and Loan crisis)
∗ 1990 – Gulf War I
∗ 1997 – Asian Crisis
∗ 1998 – Russian Crisis and the LTCM default
• 2000 – Collapse of dot-com bubble

[38] It is worth noting that although the term 'Greenspan conundrum' has been coined, the phenomenon might be easily explained on the grounds of the expectations theory of the term structure of interest rates (see e.g. Walsh 2010, Ch. 10.3.1) – if market participants expect rapid and deep interest rate cutting in the nearest future, the long-term interest rates may go down despite the current tightening of the monetary policy. Indeed, in the period 2007-2008 the federal funds rate was lowered to the range 0-0.25%.

[39] Due to methodological issues, data before and after 1986 may not be perfectly comparable. Thus this point should be considered with a certain degree of care.

* 2001 – September 11
* 2002 – Worldcom and Enron scandals
* 2003 – Gulf War II

We claim that domestic crises and periods of market distress may be, in a broader sense, perceived as potential sources of nonlinearity and state-dependency of the monetary transmission mechanism. Actually, in section 2 we discussed many micro-based premises behind the nonlinearity and state-dependency of the monetary transmission mechanism which are closely related to crises and market distresses (e.g. animal spirits, self-fulfilling prophecies, sunspots, multiple equilibria, fragile equilibrium for the Phillips curve; the liquidity trap, flight to liquidity and quality for the IS curve; the zero lower bound on interest rates for the Taylor rule). However, the problem we want to address herein is somewhat broader and rather refers to methodological issues regarding the process of economic and econometric modelling.

Usually, crises and market distresses come either unexpectedly or at an unexpected time. If we knew *a priori* the exact mechanisms of all possible crises, some of them would not have happened or we would have been much better prepared for them. We point out that such situations are beyond the models we build or perhaps even beyond the models we are able to build. Bearing in mind our cognitive limitations, we cannot tell apart our ignorance from pure randomness and what we are not able to justify within the model we attribute to stochastic shocks. Therefore, crisis situations may be perceived as bifurcation points beyond which otherwise operative models cease to work and some other more complicated mechanisms come into play.

In particular, crises and market distresses may be recognised as a manifestation that the (log)linearity assumption underlying most of the economic and econometric models has some fundamental limitations. Contemporary DSGE models are usually log-linearised around steady-states, without broader considerations to what extent this approximation is valid. In many cases no proof is proposed to assure that the found steady-state is the only one or that it is truly a stable equilibrium. Apart from this, usually little is done to show that the first-order approximation is sufficient to capture the model's fundamental properties. On the other hand, when a higher order approximation is applied, the pruning technique often serves as scissors cutting out extreme or explosive impulse responses. Finally, the log-linear approximation around the steady-state is designed to work well in close vicinity of the steady-state, while periods of crises and market distresses are usually far away from it.

Last but not least, very often crises situations are either followed or preceded by policy measures (usually regulatory and institutional ones) which change ‘the rules of the game’. It is very convenient to assume that the parameters estimated in econometric models are constant in time, but crises usually induce policymakers to introduce some structural changes and to make politicians conscious of the fact that the old political measures were wrong, poorly designed or insufficient; for example, the Financial Institutions Reform, Recovery, and Enforcement Act of 1989 and the Sarbanes-Oxley Act of 2002 were introduced in reaction to the Saving and Loan crisis and the WorldCom-Enron scandals, respectively. The former act fundamentally changed the *modus operandi* of the savings and loan industry and its safety and regulatory net, while the latter act aimed to reduce information asymmetry between company outsiders and insiders and some of its most harmful consequences. On the other hand, the Housing and Community Development Act of 1992 (e.g. introducing ‘affordable housing goals’ for Fannie Mae and Freddie Mac) and the Gramm-Leach-Bliley Act of 1999 (e.g. removing barriers in joining the activities of commercial banks, investment banks and insurance companies) are often perceived as factors contributing to the recent financial crisis.

To conclude, we hold that crises and market distresses may be perceived as a manifestation that our models are essentially and always too modest to capture all fundamentally important features of the real world even if we focus on its very tiny parts.

3.6 The Greenspan standard

In this subsection we analyse potential sources of nonlinearity and state-dependency of the monetary transmission mechanism due to the Greenspan standard, i.e. the way Alan Greenspan conducted the monetary policy as Federal Reserve chairman according to academic economists.[40] To organise our considerations we shortly discuss some principles of the Greenspan standard as were proposed by Blinder and Reis (2005)[41]. As was stated previously, bearing in mind the scope of this study we focus solely on premises which may

[40] The Greenspan standard by no means should be treated as official and explicit principles according to which Alan Greenspan conducted his monetary policy.
[41] The numbering of principles (in brackets) in the latter part of this subsection comes directly from Blinder and Rise (2005).

suggest that the monetary policy was conducted in a nonlinear or state-dependent way and thus deviated from the standard Taylor rule.

3.6.1 Option value and lack of economic straitjackets

Blinder and Reis (2005) described three principles which, taken together, suggest Greenspan's dislike for pre-commitment to any particular policy rule, economic or forecasting model:

- Keep your options open (Principle No. 1)
- Don't let yourself get trapped in doctrinal straitjackets (Principle No. 2)
- Forecasts and models, though necessary, are unreliable (Principle No. 4).

Greenspan, being a practitioner and empiricist rather than a theorist, many times expressed his doubts about the validity of economic and econometric models. He explicitly acknowledged the nonlinearity and time-variance of the real economic world, pointing out that 'an assumption of linearity may be adequate for estimating *average* relationships, but few expect that an economy will respond linearly to every aberration' and the 'relationships underlying the economy's structure change over time in ways that are difficult to anticipate' (Greenspan 2003). In the same set of remarks he also emphasised the role of irreducible uncertainty regarding the true model of the economy and conducting the monetary policy. That is why he believed in period-by-period discretion rather than rules and wanted to keep all options open (Greenspan 2004). Blinder and Reis (2005) also claimed that Greenspan 'has been remarkably flexible and adaptable to changing circumstances' and 'has been known to change his mind – without, of course, saying so – on certain issues'. This suggests that the Greenspan era could be quite heterogeneous, although in many papers this time period is treated as one homogeneous period. Indeed, studies by Gorodnichenko and Shapiro (2007), and Bae, Kim and Kim (2012), showed that the Greenspan era actually consisted of two distinct periods with a breakpoint in the late 1990s. In particular, the early period was characterised by a stronger reaction to inflation than the second period. Gorodnichenko and Shapiro (2007) claimed that credibility allowed Greenspan to take a gamble by keeping interest rates low despite very strong output growth while the private sector believed that possible policy errors would be corrected. Gorodnichenko and Shapiro (2007) also held that Greenspan put more emphasis on price level than on inflation, which is a framework favouring correction of errors in the monetary policy.

3.6.2 Avoidance of policy reversals

Blinder and Reis (2005) provided some evidence that Greenspan had a strong inclination to avoid policy reversals (Principle No. 3). Particularly, he claimed that contrary moves in the interest rates at short intervals impair a central bank's credibility. Such beliefs may also justify why he preferred to move gradually rather than to 'serve a cold turkey' – it is much safer to move step by step since after every move the way back is temporarily blocked. This principle suggests that the interest rate rule under Greenspan was history-dependent, i.e. the path of the interest rate depended on past changes in interest rates.

3.6.3 Risk management and robust pre-emptive monetary policy

Many times Greenspan (e.g. 2003, 2004) expressed the opinion that the monetary policy should be robust with respect to misspecification of the models describing the economy and against worst-case scenarios. Blinder and Reis (2005) found his monetary policy to be 'satisficing' rather than optimising and claimed that Greenspan followed a principle that 'risk management works better in practice than formal optimisation procedures – especially as a safeguard against very adverse outcomes' (Principle No. 6). At the same time, Greenspan is believed to have been an advocate of acting pre-emptively when possible (Principle No. 5), which justifies why some of his moves were in fact policy insurances against very low probable but very adverse events.[42] For example, the easing monetary policy in 1998 served as insurance against the spill-over effects of the Russian crisis and the LTCM default, even though the economy was growing strongly. Again, these considerations show that the interest rate rule under Greenspan was state-dependent and possibly based on a broader set of variables than just inflation and the output gap.

3.6.4 Recession avoidance preferences

According to Blinder and Reis (2005), Greenspan treated the Federal Reserve's dual mandate very seriously and internalised in his decisions society's strong dislike towards recessions. In particular, he followed the principle that 'recessions should be avoided and/or kept short, as should periods of growth below potential' (Principle No. 7), while aspirations should be set high, even if it is impossible to achieve all of them (Principle No. 11). The principles, taken

[42] Taleb (2007) called such events 'black swans'.

together, point towards Greenspan's recession avoidance preferences, which was econometrically confirmed by Cukierman and Muscatelli (2008) and Kim and Nelson (2006). At the same time, Blinder and Reis (2005) also provided some textual evidence supporting the view that Greenspan was more concerned about overcooling than overheating the economy. Recession avoidance preferences might also have been responsible for Greenspan's relatively passive behaviour in response to oil shocks (Principle No. 8).

3.6.5 Adverse shocks and bubbles

In 1998, after the Federal Reserve lowered interest rates in response to the LTCM default, financial markets coined the term 'Greenspan put'. The term literally refers to the put option which hedges investors against large price drops. By analogy, it was believed that in the case of a large adverse stock-market shock, the Federal Reserve would react by cutting rates and thus cushioning the asset prices plummet. At the same time, Greenspan was known for being reluctant to deflate booms and to allow asset prices to rise. Blinder and Reis (2005) held that the principle 'don't try to burst bubbles; mop up after' (Principle No. 9) was an important part of the Greenspan standard. Moreover, there are also other studies confirming the existence of the Greenspan put (e.g. Miller, Weller and Zhang 2002; Hall 2011). The principle may be perceived as another manifestation of strong recession avoidance preferences or as direct evidence of nonlinearity of the interest rate rule with respect to asset prices.

3.7 Summary

In this section we provided both extensive theoretical and empirical evidence supporting the idea of significant nonlinearities and state-dependency of the monetary transmission mechanism in the Greenspan era. In particular, we discussed globalisation, structural changes in the U.S. economy, crises and market distresses and the Greenspan standard as potential sources of nonlinearities and state-dependency of the monetary transmission mechanism. In the next section we begin the process of econometric modelling of the monetary transmission mechanism in the Greenspan era by estimating the baseline linear model of the monetary transmission mechanism and showing its empirical inadequacy.

4. Baseline model of the monetary transmission mechanism

4.1 Introduction

As was pointed out by Teräsvirta, Tjøstheim, and Granger (2010, Ch. 5.1), 'linearity testing has to precede any nonlinear modelling and estimation'. It is even all the more necessary if the estimated model nests a linear one, which is particularly the case for the econometric modelling method that is applied in this study, i.e. the smooth transition autoregressive ($STAR$) modelling framework. Therefore, in this section we specify, estimate and evaluate a baseline linear model of the monetary transmission mechanism and only later, in the following sections, do we move towards a nonlinear and state-dependent framework.

At the beginning of this section we present the applied econometric method of modelling the monetary transmission mechanism. Specifically, we formulate a simplified, stylised New Keynesian model of monetary transmission with some distinctive modifications justified by the characteristic features of nonlinearity and state-dependency modelling. Later, we describe the data we use for the estimation. Finally, we present the obtained estimates and evaluate the model from both the econometric and economic perspective.

4.2 Econometric method

Conceptually, we would like to follow the development of the New Keynesian framework and capture the dynamics described by a hybrid version of the small monetary transmission mechanism as given by equations 1.3, 1.6 and 1.12. However, bearing in mind the specific properties and limitations of nonlinear modelling, we need to introduce some modifications when compared to the small New Keynesian model of the monetary transmission mechanism in the spirit of Galí (2008, Ch. 3).

4.2.1 Functional form

As may be seen in equations 1.3 and 1.6, the intercept term is omitted in the Phillips curve and the IS curve equations. Typically, series are demeaned or detrended before estimation, and thus it is assumed that the intercept term is equal to zero. Such an action makes no distinction between the unconditional and conditional mean and, although very often practised, may create a bias in the estimated parameters. Clearly, the problem is more severe in the case of nonlinear models, for which the expected value of the function of random variables is generally not equal to the function of the expected value of random variables. As was noted by Kennedy (2008, Ch. 7), including the intercept also helps to alleviate the omitted variables problem. The most important argument for including the intercept in the estimated equations is, however, that it is required to perform some diagnostic and linearity tests. Otherwise, some tests are infeasible or test statistics have unknown distributions. Therefore, we do not omit the intercept term in neither of the estimated equations.

The standard New Keynesian model of monetary transmission incorporates expectations which are rational in the sense of Muth (1961). In other words, it is assumed that the expectations are model-consistent and thus they are the outputs rather than the inputs of the model (Evans and Honkapohja 2005). Solving such a model is mathematically nontrivial, therefore the dynamics of a system is usually only approximated around a steady-state with a system of linear equations. Intuitively, such a framework is hardly applicable for a study designed to detect nonlinearities, state-dependencies and asymmetries, i.e. phenomena which are excluded by linear approximation around a steady-state. The limitations listed below are mainly conceptual and they would not disappear even if higher orders of approximation were used:

- approximation around a steady-state is meaningful if a steady-state is existent, unique and stable – in this study the phenomenon of multiple or unstable equilibria is implicitly allowed and thus the concept of approximation around a steady-state is not applicable;
- impulse response functions based on the approximation around a steady-state are conditioned on the economy being initially in a steady-state and only later unhinged by a designed shock – in this study we are interested in the global rather than local dynamics of a system and we explicitly allow for impulse response functions which depend on the initial or historical conditions before the economy is hit by a shock;
- approximation around a steady-state works well in the close neighbourhood of a steady-state – in this study we do not restrict ourselves to shocks which are small enough to be considered as keeping the economy near a steady-state but, conversely, we want to compare the unit effects of large and small shocks.

Taking the above into consideration, we substitute the rational expectations in the sense of Muth (1961) for the exact expectations formulated on the basis of lagged model variables. It is important to note, however, that such a departure does not imply that the expectations are no longer rational – they are rational but in a broader, or rather different, sense. As was pointed out by Simon (1978), the term 'rational expectations' in the sense of Muth (1961) is ill-chosen (Simon proposed the term 'consistent expectations' instead) and there are also other forms of rationality. Although we do not label our approach precisely, one may find many similarities with:

- procedural rationality as opposed to substantive rationality (Simon 1978) – in the proposed framework the expectations may be seen as procedurally rational since they are effectively subjected to given cognitive and information limitations. Just as in real life, the economic agents do not know the true model of the economy or the data-generating process but observe (with some lag) realisations of the stochastic process upon which the expectations are formed. Therefore, in contrast to model-consistent expectations, herein the expectations are not the outcomes but the inputs of the model (Evans and Honkapohja 2005);
- exact expectations (Hansen and Sargent 1980, 1981) – conceptually, the exact expectations are non-stochastic functions of information possessed by the economic agents about the relevant state-variables governing the dynamics of the system they would like to control. In other words, instead of defining expectations in terms of model consistency, we define expectations in terms of the exact function of information available to the economic agents. Again, the first approach is closer to substantive rationality and model outcomes, while the second approach is closer to procedural rationality and model inputs;
- forecast-based expectations in the spirit of Ball (2000)[43] – formulating expectations may be seen as a forecasting exercise. The economic agents possess information on past realisations of some variables of interest and try to forecast their future behaviour with the use of given econometric tools. In the proposed framework the economic agents may be seen as forecasting on the basis of lagged values of model variables with the use of simple linear regression.

[43] Ball (2000) called his approach 'near-rational'. It should be noted, however, that this term is even more ambiguous than 'rational' since for every single definition of rationality there are many potential definitions of near-rationality. See Woodford (2010a) for a more general definition of 'near-rational expectations'.

- robust expectations (Evans and Honkapohja 2005, Hansen and Sargent 2007) – the economic agents share the experience of an econometrician and thus they want to form expectations which are robust to model misspecification. In the proposed framework, no special assumption is made with respect to the underlying model of the economy according to which the economic agents should form their expectations. Thus the expectations are robust with respect to many models which are based on the same set of endogenous variables, and no particular model is favoured.

Bearing in mind the finding that the coefficient on the real interest rate is very often wrongly signed in the IS curve (e.g. Stracca 2010), and confirmation of this finding for the data we analyse here, we substitute the current value of the real interest rate with the lagged one in the IS curve equation. Since in this study we model the behaviour of the effective federal funds rate, such a modification may also be justified on the grounds of rich empirical evidence (e.g. Cottarelli and Kourelis 1994; Borio and Fritz 1995) proving a sluggish pass-through between money market and bank lending rates. In particular, Cottarelli and Kourelis (1994) estimated (for the U.S. economy) that only 32-41% of change in the money market rate was translated into the bank lending rate on impact, while the multiplier grew to 69-97% after a quarter.

By putting the proposed modifications together, we obtain a model of the monetary transmission mechanism which consists of six equations – three structural equations and three expectations ones[44]:

$$\pi_t = \alpha_0 + \alpha_1 \pi_{t-1} + (1-\alpha_1) E_t \pi_{t+1} + \alpha_2 x_t + \varepsilon_{\pi,t} \tag{4.1}$$

$$E_t \pi_{t+1} = \beta_0 + \beta_1 \pi_{t-1} + \beta_2 x_{t-1} + \beta_3 i_{t-1} \tag{4.2}$$

$$x_t = \gamma_0 + \gamma_1 x_{t-1} + (1-\gamma_1) E_t x_{t+1} + \gamma_2 (i_{t-1} - E_t \pi_t) + \varepsilon_{x,t} \tag{4.3}$$

$$E_t x_{t+1} = \delta_0 + \delta_1 \pi_{t-1} + \delta_2 x_{t-1} + \delta_3 i_{t-1} \tag{4.4}$$

$$E_t \pi_t = \zeta_0 + \zeta_1 \pi_{t-1} + \zeta_2 x_{t-1} + \zeta_3 i_{t-1} \tag{4.5}$$

$$i_t = \theta_0 + \theta_1 i_{t-1} + \theta_2 \pi_t + \theta_3 x_t + \varepsilon_{i,t} \tag{4.6}$$

[44] The expectation equations (4.2), (4.4) and (4.5) share exactly the same set of explanatory variables because the rational expectations are defined in terms of the exact function of information available to the economic agents.

After some simple manipulations presented in Appendix A.3, the model is reducible into a three-equation reduced form which, after taking into account the $AR(1)$ nature of disturbance terms, may be presented as follows:

$$\pi_t = \phi_{11} + \phi_{12}\pi_{t-1} + \phi_{13}x_t + \phi_{14}x_{t-1} + \phi_{15}i_{t-1} + \phi_{16}\epsilon_{\pi,t-1} + \nu_{\pi,t} \qquad (4.7)$$

$$x_t = \phi_{21} + \phi_{22}\pi_{t-1} + \phi_{23}x_{t-1} + \phi_{24}i_{t-1} + \phi_{25}\epsilon_{x,t-1} + \nu_{x,t} \qquad (4.8)$$

$$i_t = \phi_{31} + \phi_{32}\pi_t + \phi_{33}x_t + \phi_{34}i_{t-1} + \phi_{35}\epsilon_{i,t-1} + \nu_{i,t} \qquad (4.9)$$

We treat the model given by equations (4.7) – (4.9) as our initial model of the monetary transmission mechanism.

4.2.2 Estimation method

Despite the recent developments of Bayesian techniques and their very common use in modern monetary economics, classical tools still remain the default choice when modelling nonlinearity and state-dependency of the monetary transmission. In particular none of the studies which were overviewed in subsection 2.5 and Appendix A1.5 employed a Bayesian approach to analyse asymmetries in the monetary transmission mechanism. In our opinion such a situation results from a greater availability of studies and books on how to model and test for nonlinearity within classical rather than Bayesian econometrics. In consequence, the modelling and testing know-how seems to be better established in the first than in the latter case, which is the main reason why we follow a classical approach as well.

A typical New Keynesian model with rational model-consistent expectations requires that one employs an estimation technique which is potent to alleviate the problem of endogeneity of model-consistent expectations. The usually exploited Generalised Method of Moments (GMM) has proved to render highly variant estimates with respect to the sample selection and the list of instrument variables, even for linear models (see e.g. Donald, Imbens and Newey 2009).[45] The problems of weak instruments and large variance of the estimators are yet more severe for nonlinear models because they usually require a longer list of instrument variables (due to the greater number of estimated parameters in the model itself or during the process of

[45] One may expect that these problems contributed to the success of Bayesian techniques in estimating New Keynesian models.

testing linearity, which very often incorporates polynomial approximations) and the system of moment equations they yield is much more difficult to solve than for the linear case. Since instrument variables correspond to the assumed information set of rational economic agents, while moment conditions represent the process of 'extracting information' from instrument variables, the problem is far from being purely technical. Moreover, links among being independent, orthogonal and uncorrelated are weaker for nonlinear than for linear models[46], which creates additional ambiguity as to how to specify moment conditions.[47] Domínguez and Lobato (2004) also proved that in a nonlinear setting, GMM estimators are not necessarily consistent because 'the GMM objective function may have several global minima'.

On a more practical side, nonlinear models estimated via GMM may need longer time series than those estimated via Least Squares (see Appendix A.4 for a small experiment). Bearing in mind that in the previous paragraph we decided to substitute model-consistent expectations with the exact expectations and to substitute the current real interest rate with the lagged one, there is no longer any special reason to estimate the model using GMM. Since the problem of endogeneity is not *a priori* existent, we should rather stick to Least Squares estimators which, in such a case, are more efficient than GMM estimators. Therefore, in the presence of an explicit $AR(1)$ disturbance term we estimate the model using the Nonlinear Least Squares method.

4.2.3 Data

The analysed sample coincides with the Greenspan era, which spans from 1987Q3 to 2005Q4 (73 observations). The baseline data set consists of the:

- annualised quarterly growth rate of a seasonally adjusted GDP deflator (in percentage points) as a measure of π_t;
- output gap estimates by the Congressional Budget Office (in percentage points) as a measure of x_t;
- quarterly average effective federal funds rate (in percentage points) as a measure of i_t.

[46] See Rodgers, Nicewander and Toothaker (1984) for a short discussion on the differences among linearly independent, orthogonal and uncorrelated variables.

[47] It is also worth noting that for linear models the OLS estimator can easily be obtained as a special case of the GMM estimator if the explanatory variable and instrument variable lists are one and the same. On the other hand, such a property does not generally hold for nonlinear models.

Although the employed variables are in line with many papers dealing with the monetary transmission mechanism, it is particularly worth stressing the importance of the output gap measure in the context of nonlinear modelling. As was already discussed in paragraph 2.2.3, simulations by Laxton, Rose and Tetlow (1993) showed that simple univariate detrending methods (including the HP filter) should be avoided when modelling nonlinearity since they seriously underestimate the true degree of nonlinearity in economic relationships. Instead, the authors proposed to use a combination of detrending methods and structural modelling, which is a method that is exactly exploited by the Congressional Budget Office to estimate the potential output and the output gap.

4.3 Estimation results

Table 4.1 presents the estimates of the initial model of the monetary transmission mechanism. Since the model is estimated in its reduced form, most of the estimated parameters in the inflation and output gap equations are not very informative themselves. However, it is easy to note that the estimate of parameter ϕ_{13}, which is a mapped one-to-one structural parameter α_2, is very low and statistically insignificant at a very high significance level (p-value $= 0.9154$). Bearing in mind that nonlinear modelling requires a relatively large number of degrees of freedom and that the baseline model should be possibly parsimonious, we also estimate an alternative version of the inflation equation in which the current value of the output gap is omitted.

Table 4.1 The estimates of the initial model of the monetary transmission mechanism and the alternative version of the inflation equation (effective sample 1988Q1-2005Q4, Nonlinear Least Squares method).

Eq.	$\phi_{\dots 1}$	$\phi_{\dots 2}$	$\phi_{\dots 3}$	$\phi_{\dots 4}$	$\phi_{\dots 5}$	$\phi_{\dots 6}$	$\bar{R}^2$	AIC	SIC
π_t	0.3891 [0.0361]	0.9083 [0.0000]	0.0132 [0.9154]	0.0427 [0.7369]	-0.0286 [0.3282]	-0.3540 [0.0063]	0.6026	1.8653	2.0550
π_t	0.3949 [0.0267]	0.9063 [0.0000]	-	0.0556 [0.1308]	-0.0288 [0.3206]	-0.3506 [0.0062]	0.6084	1.8377	1.9958
x_t	0.2235 [0.3816]	-0.0554 [0.5097]	0.9319 [0.0000]	-0.0253 [0.5543]	0.2708 [0.0479]	-	0.9066	1.5177	1.6758
i_t	1.1543 [0.0543]	0.0710 [0.2690]	0.2455 [0.0020]	0.7294 [0.0000]	0.8554 [0.0000]	-	0.9799	0.6309	0.7890

p-values in square brackets

The residual diagnostic tests (Table 4.2) performed here allow us not to reject the (individual) hypotheses of: normal distribution, no autocorrelation (up to 12 lags) and homoscedasticity of residuals for all equations at a 1% significance level. If the significance level is raised to 5%, the χ^2 version of the Breusch-Godfrey test signals a problem with the autocorrelation in the initial specification of the inflation equation. Finally, pushing up the significance level further to 10% requires that we reject the null hypothesis of no autocorrelation, homoscedasticity (Breusch-Pagan test) and normal distribution of residuals for the inflation equations (in both the initial and alternative specification), the output gap equation and the interest rate equation, respectively. The obtained results support the idea of substituting the initial specification of inflation equation with the alternative one, since then the model residuals have desirable properties at the typically employed 5% significance level.

Table 4.2 P-values of residual diagnostic tests (π_t^A stands for an alternative specification of the inflation equation)

Equation	H_0: normal distribution	H_0: no autocorrelation		H_0: homoscedasticity					
	Jarque-Bera	Breusch-Godfrey*		Breusch-Pagan		ARCH*		White	
		F	χ^2	F	χ^2	F	χ^2	F	χ^2
π_t	0.137	0.053	0.043	0.851	0.840	0.961	0.943	0.780	0.762
π_t^A	0.129	0.061	0.054	0.736	0.724	0.963	0.945	0.750	0.734
x_t	0.925	0.479	0.392	0.074	0.075	0.764	0.716	0.487	0.470
i_t	0.088	0.652	0.558	0.325	0.314	0.877	0.839	0.431	0.415

* up to 12 lags

It is important to note that the variance-covariance matrix of the estimated residuals may be treated as diagonal no matter whether we look at the initial or alternative specification of the inflation equation (Table 4.3). The estimated residuals are not only individually uncorrelated among equations at a high significance level but also the p-value of the joint hypothesis (that all non-diagonal elements of the analysed variance-covariance matrix are equal to zero) is above any typically employed significance level – an LR test with the first-order Bartlett correction reports a p-value being equal to 0.8766 and 0.9036 for the initial and the alternative specification, respectively. Such an attribute is favourable from the perspective of both the properties of the Least Squares estimator and impulse response analysis. In the latter case there is no special need to apply any orthogonalisation procedure since we may already treat the residuals as being orthogonal.

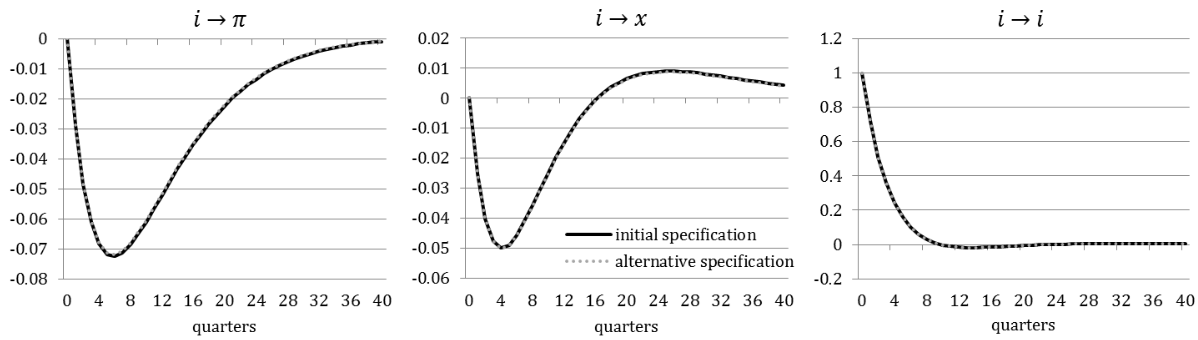
Table 4.3 Correlation matrices of the estimated residuals

	$\hat{v}_{\pi,t}$	$\hat{v}_{x,t}$	$\hat{v}_{i,t}$
$\hat{v}_{\pi,t}$	1		
$\hat{v}_{x,t}$	-0.1011 [0.4016]	1	
$\hat{v}_{i,t}$	0.0107 [0.9294]	-0.0489 [0.6859]	1
	p-values in square brackets		

	$\hat{v}_{\pi^A,t}$	$\hat{v}_{x,t}$	$\hat{v}_{i,t}$
$\hat{v}_{\pi^A,t}$	1		
$\hat{v}_{x,t}$	-0.0902 [0.4543]	1	
$\hat{v}_{i,t}$	0.0123 [0.9189]	-0.0489 [0.6859]	1
	p-values in square brackets		

Bearing in mind the scope of this thesis, we are particularly interested in the model's response to monetary policy shock – the only type of shock which is structurally identified in the model owing to one-to-one mapping between the structural and reduced form of the Taylor rule. Figure 4.1 presents the estimated impulse responses of the three endogenous variables to the unit (i.e. equal to one percentage point) one-off shock in the interest rate equation. Virtually, there is no difference between the impulse response functions under the initial and alternative specification of the model of the monetary transmission. In both cases, the observed patterns are consistent with the patterns presented in the literature (see e.g. Galí 2008, Ch. 3).

Figure 4.1 Impulse responses of π_t, x_t and i_t to unit one-off shock in i_t for the initial and the alternative specification of the model of the monetary transmission mechanism



Since, as it was aforementioned, nonlinear modelling requires relatively large number of degrees of freedom and the baseline model should be possibly parsimonious, we set the alternative specification (i.e. initial specification of the inflation equation is substituted with the alternative one) as our baseline specification of the model of the monetary transmission mechanism. Under such a specification the performed diagnostic tests report no problems with autocorrelation, heteroscedasticity or lack of normal distribution of residuals at 5% significance level. One another advantage of such an approach is that now all the equations have the same number of the estimated parameters, what facilitates the procedure of testing for nonlinearity and state-dependency, and makes the test results more comparable among the equations.

To avoid possible mistakes with numeration of the parameters due to omitting ϕ_{13} in the inflation equation, we rewrite the notation of the baseline model of the monetary transmission mechanism by substituting ϕ with φ. In general $\phi_{ij} = \varphi_{ij}$ but $\phi_{14} = \varphi_{13}$, $\phi_{15} = \varphi_{14}$, $\phi_{16} = \varphi_{15}$:

$$\pi_t = \varphi_{11} + \varphi_{12}\pi_{t-1} + \varphi_{13}x_{t-1} + \varphi_{14}i_{t-1} + \varphi_{15}\epsilon_{\pi,t-1} + \nu_{\pi,t} \tag{4.10}$$

$$x_t = \varphi_{21} + \varphi_{22}\pi_{t-1} + \varphi_{23}x_{t-1} + \varphi_{24}i_{t-1} + \varphi_{25}\epsilon_{x,t-1} + \nu_{x,t} \tag{4.11}$$

$$i_t = \varphi_{31} + \varphi_{32}\pi_t + \varphi_{33}x_t + \varphi_{34}i_{t-1} + \varphi_{35}\epsilon_{i,t-1} + \nu_{i,t} \tag{4.12}$$

Throughout the rest of the text we will refer to the model consisting of equations (4.10) – (4.12) as our baseline model of the monetary transmission mechanism.

4.4 Summary

In this section we introduced and estimated the baseline model of the monetary transmission mechanism. The performed diagnostic tests and the impulse response analysis prove that the model has desirable properties from both the econometric and economic perspective. The presented baseline model of the monetary transmission will later serve as a reference linear model when modelling nonlinearities and state-dependency of the monetary transmission mechanism. In the next section we perform nonlinearity and state-dependency tests, and we show that the baseline model of the monetary transmission mechanism hides some peculiarities which are not usually detected when the typical procedure of econometric modelling is applied.

5. Testing for nonlinearity and state-dependency of the monetary transmission mechanism

5.1 Introduction

Before directly proceeding to modelling nonlinearity and state-dependency, we perform some simple tests which are capable of detecting continuous forms of nonlinearity and state-dependency. In particular, we follow the general idea of the Ramsey Regression Equation Specification Error Test (Ramsey RESET test) and we verify whether polynomial and interaction terms are statistically significant once they are included in the baseline model of the monetary transmission mechanism. Conversely to common practice, we develop and discuss the testing procedure which is based on the Lagrange multiplier (LM) test instead of the Wald or likelihood ratio (LR) tests. Such an approach is aimed at providing possibly robust evidence of the existence of nonlinearities and state-dependencies in the baseline model of the monetary transmission mechanism regardless of the properties of the particular unrestricted (nonlinear or state-dependent) model.

5.2 Testing for nonlinearity

In this subsection we test the null hypothesis of linearity against the alternative hypotheses of nonlinearity which may be approximated with the polynomial and interaction terms in the spirit of the Taylor formula. At the beginning we perform the standard Ramsey RESET test with the use of fitted values from the linear equations, while later we also carry out more detailed tests based on the right-hand side variables. As definition 1 (see subsection 1.4) states, while testing for nonlinearity we should be interested only in the products and linear combinations of variables which are already included in the set of explanatory variables, for each equation separately.

It is important to emphasise that execution of equation specification error tests is not common practice in the case of micro-founded models of the monetary transmission mechanism. Usually, the functional form of the model is derived in a rigorous way under the DSGE framework and is assumed to be correct despite the fact that the model is typically log-linearised and sometimes estimated in its reduced form. In other words, when it comes to estimation, the functional form of the model is usually taken for granted and the results of the specification error tests are not reported. This context makes the results of the Ramsey RESET tests all the more interesting.

5.2.1 Standard Ramsey RESET test

The intuition behind the standard Ramsey RESET test is that the model is wrongly specified if the powers of the fitted values obtained from the baseline linear model are statistically significant once they are additionally included in that model. Technically, implementation of the standard Ramsey RESET test relies on the following two-stage algorithm:

1. Estimate the model:

   $$y_t = \beta_0 + \sum_{i=1}^{I} \beta_i z_{it} + \varepsilon_t \tag{5.1}$$

   and collect the fitted values $\hat{y}_t$.

2. Estimate the model:

   $$y_t = \gamma_0 + \sum_{i=1}^{I} \gamma_i z_{it} + \sum_{j=1}^{J} \theta_j \hat{y}_t^j + \epsilon_t \tag{5.2}$$

   and test whether $\bigwedge_{j=1}^{J} \theta_j = 0$.

Typically, the joint null hypothesis, $\bigwedge_{j=1}^{J} \theta_j = 0$, is tested with the use of the simple F-test or Wald test regardless of the residuals' properties in the unrestricted model. Nevertheless, it is easy to generalise the procedure and make it robust to problems with autocorrelation or heteroscedasticity of the residuals by substituting the standard variance-covariance matrix with a robust one in the formula for the test statistic (see e.g. Stock and Watson 2012, Ch. 18.3). In particular, the White matrix may be used when the test equation suffers from heteroscedasticity, while the Newey-West matrix is suitable if there are problems with autocorrelation, or both autocorrelation and heteroscedasticity.

Taking into account that correctly carrying out the Ramsey RESET test requires information on residual diagnostic tests for the test equation (i.e. unrestricted model), Table 5.1 reports not only the p-values of the standard Ramsey RESET tests but also the p-values of the Breusch-Godfrey and Breusch-Pagan tests. The results reveal that the output gap equation is the only equation which suffers from a wrongly specified functional form. Such an observation is, to some extent, consistent with the findings of Stracca (2010), who claimed that the IS curve is not a structural relationship.[48] At the same time, the inclusion of additional terms raised the p-value of the Breusch-Pagan test in the output gap equation, which is in line with the point made by Kennedy (2008, Ch. 8) that the detected heteroscedasticity may very often be perceived as a symptom of an incorrect functional form rather than true heteroscedasticity of the error term. Similarly, the additional terms raised the p-value of the Breusch-Godfrey test in the case of the inflation equation, which supports the view that problems of an incorrect functional form and autocorrelation of the error term are very often interrelated in practice.[49]

Table 5.1 P-values of Ramsey RESET tests and p-values of Breusch-Godfrey and Breusch-Pagan tests for Ramsey RESET test equations

Equation	Maximum power (J) of fitted terms	H_0: additional terms jointly insignificant		H_0: no autocorrelation		H_0: homoscedasticity	
		Ramsey RESET test		Breusch-Godfrey*		Breusch-Pagan	
		F	χ^2	F	χ^2	F	χ^2
π_t	3	0.9592	0.9592	0.3942	0.2890	0.2876	0.2765
	4	0.6397	0.6376	0.5151	0.3786	0.2545	0.2454
x_t	3	0.0050	0.0032	0.5561	0.4320	0.4612	0.4423
	4	0.0132	0.0088	0.6579	0.5176	0.1751	0.1718
i_t	3	0.9801	0.9801	0.7127	0.5917	0.2683	0.2583
	4	0.6343	0.6321	0.7079	0.5715	0.3506	0.3353

* up to 12 lags

The literature suggests that the results of the standard Ramsey RESET test should be considered with the utmost caution. In particular, Greene (2012, Ch. 5.9) argued that the properties of the presented two-stage algorithm, where fitted values from (5.1) enter as regressors in (5.2), are dubious. Moreover, the standard Ramsey RESET test 'gives no indication what the researcher should do next if the null model is rejected' since 'the rejection of the null model does not imply any particular alternative' (Greene 2012, Ch. 5.9).

Despite its obvious drawbacks, the standard Ramsey RESET test shows that in the case of the output gap equation, the common practice of treating the functional form of the model of the monetary transmission mechanism as correct may be somewhat too optimistic. In the next paragraph we investigate the problem of misspecification more in-depth, and we try to identify the specific explanatory variables which are responsible for contingent nonlinearities.

48 It should be noted, however, that herein the IS curve is estimated in its reduced form and the current real interest rate is substituted with the lagged one.

49 A classic example is when a linear trend is fitted to data which were generated with the use of the quadratic function. Even if the observations lie on only one half of the parabola and the goodness of fit is very high, the residuals will be highly autocorrelated.

5.2.2 Right-hand side LM version of the RESET-type test for nonlinearity

The Ramsey RESET test may be modified to include powers of the right-hand side (i.e. explanatory) variables rather than powers of the fitted values. It is also possible to expand the test equation with some interactions among the explanatory variables in the spirit of the Taylor approximation of a multivariable function. However, since the estimation of a complex test equation consumes a large number of degrees of freedom and additional terms are highly collinear, the practical feasibility of testing is seriously limited by the number of observations. Bearing in mind these limitations and the fact that we would like to identify specific explanatory variables which are responsible for possible nonlinearities, we may want to test whether $\bigwedge_{i=1}^{I}\bigwedge_{j=1}^{J}\theta_{kij}=0$ for $k=1,\dots,I$ in the following sequence of equations:

$$y_t=\gamma_{k0}+\sum_{i=1}^{I}\gamma_{ki}z_{it}+\sum_{i=1}^{I}\sum_{j=1}^{J}\theta_{kij}z_{it}z_{kt}^{j}+\epsilon_{kt} \qquad \text{for } k=1,\dots,I \qquad (5.4)$$

In other words, in every single test equation only one explanatory variable (denoted as z_{kt}) is allowed to be a potential source of nonlinearity. The obvious drawback of such a procedure of testing is that we do not control for the overall significance level. On the other hand, when testing for various forms or sources of nonlinearity this is the rule rather than the exception due to the aforementioned practical limitations.

Although there exist many ways of testing linearity[50] the proposed test distinguishes itself with a unique set of desirable characteristics – it is:

- parametric,
- consistent against many nonlinear alternatives,
- recommended as a linearity test against some particular nonlinear alternatives, e.g. smooth transition autoregressive ($STAR$) models, which will be estimated in section 6.

Taking above into consideration, the choice of the proposed test may be seen as a part of the adopted framework of modelling nonlinearity.

A typical approach when testing $\bigwedge_{i=1}^{I}\bigwedge_{j=1}^{J}\theta_{kij}=0$ in (5.4) is to estimate the unrestricted model and to use the Wald test or to estimate both unrestricted and restricted models and to use the LR test. We argue, however, that both solutions are questionable because:

[50] see e.g. Teräsvirta, Tjøstheim, and Granger (2010, Ch. 5 – 7) for discussion and further references.

- equation (5.4) serves only as a Taylor-type approximation of an unknown nonlinear functional form, the properties of which are not exactly recognised – e.g. a nonlinear model may include some parameters which are not identified under the null hypothesis. Then both the Wald and LR tests might be invalid.
- testing whether $\bigwedge_{i=1}^{I} \bigwedge_{j=1}^{J} \theta_{kij} = 0$ in (5.4) requires having knowledge of the residuals' properties in the unrestricted model. Although in the case of the Wald test the problem may be alleviated by applying robust versions of the variance-covariance matrix, if residuals in (5.4) are autocorrelated or heteroscedastic, the residuals in (5.4) do not necessarily share their properties with an unknown nonlinear model. In the case of the LR test the problem of autocorrelation, heteroscedasticity or discrepancy between the residuals' properties in restricted and unrestricted models is difficult to overcome because the number of degrees of freedom in the LR statistic depends on the difference in the number of parameter space dimensions between the restricted and unrestricted model.
- the Wald test is not invariant to the formulation of (nonlinear) hypotheses and units in which the variables are measured, especially in small samples (Kennedy 2008, Ch. 4.5). Although the hypothesis $\bigwedge_{i=1}^{I} \bigwedge_{j=1}^{J} \theta_{kij} = 0$ is linear with respect to parameters θ_{kij}, the underlying hypothesis linking the unknown nonlinear model and the restricted linear model might be nonlinear. Then the method of approximation adopted in (5.4) may bias the Wald statistic.

Bearing in mind the limitations of the Wald and LR tests as discussed above, we propose to base the testing procedure on the LM test, i.e. the only test of the three which does not require that the unrestricted model has to be estimated and favours neither of the locally equivalent unknown nonlinear models (see Teräsvirta, Tjøstheim, and Granger 2010, Ch. 5.4) Although the three tests are asymptotically equivalent (Engle 1984), the LM test was shown to reject the null hypotheses the least often in linear models in small samples. Berndt and Savin (1977) proved that the values of the test statistics satisfy the inequality $Wald \geq LR \geq LM$. Thus it is important to note that the LM test may be somewhat oversized.[51] On the other hand, Kohler

[51] The discussion provided by Kennedy (2008, Ch. 4.5) concluded that whenever both restricted and unrestricted forms of the model are available, the LR test should be preferred in small samples.

(1982) showed that all three tests have the same power properties[52], which means that the choice among the three tests may be, at least partially, based on the researcher's level of conservativeness. Since treating the model of the monetary transmission mechanism as linear is well grounded and questioning such an approach should be supported with sound evidence, we find the conservative LM test to be an appropriate choice.

By being conservative we also avoid the procedure of carrying out an LM test that is based on the outer product of the gradient (OPG) and the uncentred R^2 from the regression of ones on the scores; a procedure which was found to result in overestimation of the LM statistic (see Kennedy 2008, Ch. 4.5 for a discussion). Instead, we apply the testing procedure that is recommended by Teräsvirta, Tjøstheim and Granger (2010, Ch. 5.3):

1. Estimate the model (5.4) under the null hypothesis of linearity, i.e. estimate:

$$y_t = \gamma_0 + \sum_{i=1}^{I} \gamma_i z_{it} + \epsilon_t \tag{5.5}$$

2. Collect the residuals e_t, the number of estimated parameters p_0 and compute the residual sum of squares SSR_0.
3. Estimate the following model:

$$e_t = \gamma_{k0} + \sum_{i=1}^{I} \gamma_{ki} z_{it} + \sum_{i=1}^{I} \sum_{j=1}^{J} \theta_{kij} z_{it} z_{kt}^{j} + \epsilon_{kt} \qquad \text{for } k = 1, \dots, I \tag{5.6}$$

4. Collect the number of estimated parameters p_1 and compute the residual sum of squares SSR_1
5. Compute the χ^2 or the F version of the LM-test statistic:

$$LM_{\chi^2} = T \frac{SSR_0 - SSR_1}{SSR_0} \qquad \xrightarrow{D} \chi^2(p_1 - p_0) \tag{5.7}$$

$$LM_F = \frac{(SSR_0 - SSR_1)/(p_1 - p_0)}{SSR_1/(T - p_1)} \qquad \overset{approx.}{\sim} F(p_1 - p_0, T - p_1) \tag{5.8}$$

[52] More precisely, once the sizes of the three tests are equalised, their powers will be equal as well, even in small samples.

Teräsvirta, Tjøstheim and Granger (2010, Ch. 5.3.2 and 16.3.2.) recommended that the χ^2 statistic be used in large samples, while the F version should be preferred in small and moderate samples due to its much better size properties, especially when the dimension of the null hypothesis is large.

The tests (Table 5.2) performed here show that only the output gap equation exhibits statistically significant nonlinearities (with respect to x_{t-1}) at a 5% significance level and only for $J = 4$.[53] Taking into account that residuals from our baseline model cease to reveal desirable properties when the significance level is raised to 10% (see Table 4.2), we should not interpret p-values $\in [5\%; 10\%]$ as evidence of nonlinearity at a 10% significance level.

Table 5.2 P-values of right-hand-side LM RESET-type test for nonlinearity

z_{kt}^{j}	inflation equation				output gap equation				interest rate equation			
	Maximum power $J = 3$		Maximum power $J = 4$		Maximum power $J = 3$		Maximum power $J = 4$		Maximum power $J = 3$		Maximum power $J = 4$	
	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2
π_{t-1}	0.800	0.734	0.887	0.827	0.828	0.768	0.261	0.207	0.472	0.396	0.499	0.410
x_{t-1}	0.151	0.122	0.243	0.193	0.149	0.121	0.016	0.018	0.159	0.128	0.249	0.198
i_{t-1}	0.154	0.124	0.115	0.095	0.674	0.596	0.674	0.579	0.086	0.071	0.206	0.164
π_t	-	-	-	-	-	-	-	-	0.371	0.305	0.643	0.548
x_t	-	-	-	-	-	-	-	-	0.131	0.106	0.307	0.244

The results obtained here may be perceived as consistent with the results of the standard Ramsey RESET test, which also showed that the output gap equation is the only equation that suffers from an incorrect (*implicitly* nonlinear) functional form. We argue, however, that such a conclusion is probably too optimistic. In the next paragraph we perform tests which may be perceived as an abutment point where testing for nonlinearity meets testing for state-dependency. Specifically, we verify the existence of indirect forms of nonlinearity according to which the model parameters depend on the measures of central tendency or dispersion of the model variables. Since the current value of a particular variable may affect the current estimates of central tendency or dispersion, the actual relation among model variables may be nonlinear.

[53] Teräsvirta, Tjøstheim and Granger (2010, Ch. 16.3.2.) recommended that $J = 3$ be used, while Escribano and Jordá (1999) suggested $J = 4$.

5.2.3 Testing for indirect forms of nonlinearity

Many of the theoretical concepts presented in section 2 are consistent with the parameters of the Phillips curve, the IS curve or the Taylor rule, being dependant on measures of central tendency or dispersion of the equation variables. In some cases such a prediction is explicitly put forward (e.g. costly adjustment and Lucas models for the Phillips curve or the cumulative prospect theory for the IS curve), while in many other cases the link is implicit or more subtle.

Foremost, we argue that some of the theoretical concepts behind the nonlinearity of equations of the monetary transmission model fail to provide a rigorous distinction between simple nonlinearity and state-dependency in which a measure of central tendency is a 'state' variable. In other words, it is not always unequivocal whether the equation is nonlinear with respect to a specific variable or perhaps state-dependent with respect to a point estimate of central tendency of that variable. For example, imperfect credibility models propose that the shape of the Phillips curve may depend on variables influencing the central bank's credibility – since the exhaustive set of such variables is unknown, one may expect that not only the actual level but also the average level and variance of inflation or the output gap may affect the central bank's credibility. Under such circumstances testing for indirect forms of nonlinearity may be seen as a robustness check for the results of the standard nonlinearity tests.

Second, point estimates of central tendency or dispersion for the inflation, output gap and interest rate may serve as proxies of the business or monetary cycle. Since many of the discussed concepts predict that the equation parameters may vary along the business or monetary cycle (e.g. as in the case of the IS curve), it seems reasonable to express such cycles in terms of point estimates of central tendency or dispersion for endogenous variables.

Taking the above into consideration, we propose to test indirect forms of nonlinearity of the monetary transmission equations with respect to two simple measures – one of central tendency and one of dispersion. We estimate the point measures of central tendency and dispersion with the sample mean (SM – sample mean) and sample unbiased variance (SV – sample variance), respectively, over a four-quarter horizon.[54]

The procedure of testing is similar as in the previous paragraph but is based on a slightly modified battery of test equations which take into account that state variables do not explicitly

[54] The formulas are as follows: $y_t^{SM} = \frac{1}{4}\sum_{i=0}^{3} y_{t-i}$ for the sample mean and $y_t^{SV} = \frac{1}{3}\sum_{i=0}^{3}(y_{t-i} - y_t^{SM})^2$ for sample variance.

but only implicitly belong to the set of explanatory variables in the baseline linear model. Instead of (5.6), the test equations take the following form:

$$e_t = \gamma_{k0} + \sum_{i=1}^{I} \gamma_{ki} z_{it} + \sum_{j=1}^{J} \vartheta_{kj} s_{kt}^{j} + \sum_{i=1}^{I} \sum_{j=1}^{J} \theta_{kij} z_{it} s_{kt}^{j} + \epsilon_{kt} \text{ for } k = 1, \dots, K \qquad (5.9)$$

The term $\sum_{j=1}^{J} \vartheta_{kj} s_{kt}^{j}$ captures the possibility of the standard omitted variable problem, which was non-existent in the previous paragraph, while the term $\sum_{i=1}^{I} \sum_{j=1}^{J} \theta_{kij} z_{it} s_{kt}^{j}$ refers to more complex forms of state-dependency according to which the parameters on the explanatory variables are functions of variable s_{kt}. Taking both terms into consideration, in line with the presented procedure of testing, we test the null hypotheses that $\bigwedge_{i=1}^{I} \bigwedge_{j=1}^{J} \vartheta_{kij} = 0$ and $\bigwedge_{i=1}^{I} \bigwedge_{j=1}^{J} \theta_{kij} = 0$ for $k = 1, \dots, K$.

The tests (Table 5.3) performed here show that in many cases the null hypothesis of linearity is rejected at a standard 5% significance level. Specifically, every equation exhibits statistically significant state-dependency with respect to at least one measure of central tendency, while the interest rate equation is additionally state-dependent with respect to sample variance of the output gap.

Table 5.3 P-values of tests for indirect forms of nonlinearity

s_{kt}^{j}	inflation equation				output gap equation				interest rate equation			
	Maximum power $J = 3$		Maximum power $J = 4$		Maximum power $J = 3$		Maximum power $J = 4$		Maximum power $J = 3$		Maximum power $J = 4$	
	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2
π_{t-1}^{SM}	0.211	0.168	0.288	0.224	0.074	0.064	0.030	0.032	0.094	0.079	0.095	0.082
x_{t-1}^{SM}	0.415	0.335	0.658	0.543	0.035	0.033	0.014	0.019	0.092	0.077	0.066	0.061
i_{t-1}^{SM}	0.014	0.016	0.024	0.027	0.464	0.377	0.114	0.096	0.006	0.008	0.004	0.008
π_{t-1}^{SV}	0.978	0.959	0.982	0.959	0.403	0.324	0.632	0.517	0.230	0.183	0.198	0.157
x_{t-1}^{SV}	0.432	0.350	0.208	0.164	0.223	0.177	0.277	0.217	0.005	0.007	0.018	0.023
i_{t-1}^{SV}	0.351	0.280	0.276	0.215	0.060	0.053	0.129	0.107	0.607	0.511	0.421	0.329

Although it is infeasible to precisely verify the theoretical concepts presented in paragraphs 2.2.2, 2.3.2 and 2.4.2 before estimation of the models incorporating the detected state-dependencies, we suggest some ‘potential consistency’ links between the detected state-dependencies and the aforementioned theoretical concepts.

The inflation equation exhibits robust state-dependency with respect to the measure of central tendency of the interest rate. The explanation for this may be twofold. First, the interest rate is highly correlated with the (central bankers') inflation expectations, which may give support to, e.g. costly adjustment or downward wage rigidity models. Moreover, the average level of the interest rate may serve as a proxy of the central bank's willingness to curb inflation, which is potentially consistent with imperfect credibility models.

In the case of the output gap equation, state-dependency is detected with respect to the measure of central tendency of the output gap. Such an observation is potentially consistent with the phenomena of flight to quality and liquidity, credit channel theory and cumulative prospect theory. Furthermore, a sample mean of inflation was also found to be a source of state-dependency of the output gap equation. Although none of the concepts presented in paragraph 2.3.2 explicitly put forward such a relationship, the result may be perceived as possibly coherent with the phenomena of flight to quality and liquidity (the inflation influences the market sentiment) or the credit channel theory (the inflation has an impact on the enterprises' balance sheets and the relative wealth of the lenders and borrowers).

The interest rate equation is found to be state-dependent with respect to the measure of the central tendency of the interest rate. The result may give support to an opportunistic approach to disinflation and the importance of the zero lower bound. Additionally, the detected state-dependency with respect to the measure of dispersion of the output gap is potentially consistent with the central bankers' non-convex loss function and nonlinear weighting of probabilities, as well as uncertainty models (3) and (4) in paragraph 2.4.2. It is also worth noting that the revealed state-dependencies may be linked to some aspects of the Greenspan standard reported in subsection 3.6 which are hardly distinguishable from the general concepts behind the nonlinearity or state-dependency of the Taylor rule.

5.3 Testing for state-dependency

Similarly as in the previous subsection, here we test the null hypothesis of state-independency against the alternative hypotheses of state-dependency which may be approximated with the polynomial and interaction terms in the spirit of the Taylor formula. The general idea of testing is analogous as in the previous paragraph and is based on the same form of test equations (5.9).

In this subsection, however, we test for state-dependency with respect to variables that do not explicitly depend on endogenous variables. The choice of potential 'state' variables is based on the literature survey – the selected variables are grouped into 10 main categories which correspond to the theoretical sources of state-dependency which were discussed in sections 2 and 3. Paragraphs 5.3.1 – 5.3.4 are supposed to meet the general premises behind the state-dependency of the monetary transmission mechanism (section 2), while paragraphs 5.3.5 – 5.3.10 are related to premises which are specific to the Greenspan era (section 3).

Whenever there are many variables which may serve as proxies of sources of state-dependency and the choice among them seems to be very subjective, we tend to test for state-dependency with respect to a broad set of potential 'state' variables. Such a procedure may be seen as a built-in robustness check. It is also important to emphasise that we are not particularly interested in state-dependency with respect to specific individual variables but with respect to the discussed sources of state-dependency which are only approximated by the selected (proxy) variables.

Before proceeding with the testing, we orthogonalise every potential 'state' variable against the time trend and the model variables.[55] The first treatment aims to explicitly separate the problem of state-dependency from the problem of time-dependency because some variables, although globally stationary, may exhibit trends during the estimation sample. The second modification helps to alleviate the fact that many macroeconomic variables, including those chosen as potential 'state' variables, are highly collinear and correlated with the model variables. In consequence, it would be naive to perceive a simple three-equation monetary transmission model as a closed-loop system. Then a proposed orthogonalisation allows, with very careful forethought, to treat the potential 'state' variables as being exogenous during estimating of the model and calculating the generalised impulse response functions.[56]

5.3.1 State-dependency with respect to measures of business cycle and climate

Many of the concepts presented in section 2 predict that equations constituting the monetary transmission mechanism may be state-dependent with respect to measures of business cycle and climate. *Capacity constraint* models explicitly claim that the slope of the Phillips curve should depend on the level of capacity utilisation, while the concepts of *procyclical competitiveness* or *procyclical elasticity of demand* propose that parameters of the Phillips

[55] Technically, we collect residuals from simple regression in which a 'state' variable is a dependent variable, while the constant, time trend, π_t, x_t and i_t are explanatory variables.

[56] Again, it is important to note that concepts of linearly independent, orthogonal and uncorrelated variables are not equivalent (Rodgers, Nicewander and Toothaker 1984).

curve may vary along the business cycle. Similarly, the *credit channel* theory and concepts of *flight to quality/liquidity* predict that the slope of the IS curve may depend on the level of economic activity, business climate and market sentiment. Consumer sentiment is also an intuitive variable that may affect the level of reference point which is believed to influence the shape of the IS curve according to the *cumulative prospect theory*. Finally, business climate measures may play a fundamental role in shaping the Taylor rule, e.g. when central bankers have *asymmetric preferences*, follow *the opportunistic approach to disinflation* or are *uncertain about the level of economic activity* or *model's parameters*.

Taking the above considerations into account, we test the state-dependency of monetary transmission with respect to four measures of the business cycle and climate as presented in Table 5.4 (see Appendix A.5 for a detailed description of the data).

Table 5.4. The selected measures of business cycle and climate

Tag	Short description
cu_t	Capacity utilization
ai_ma_t	Chicago Fed National Activity Index: three month moving average
ai_di_t	Chicago Fed National Activity Index: diffusion index
cs_t	University of Michigan: Consumer Sentiment Index©

The obtained results (see Table 5.5) suggest that the shape of the monetary transmission mechanism may vary along the business cycle mainly due to the state-dependency of the output gap and the interest rate equations, which exhibit statistically significant state-dependency with respect to each time series and the results are almost insensitive to the choice of maximum power ($J = 3$ or $J = 4$) and the test statistic (F or χ^2). Surprisingly, although many of the concepts discussed in Section 2 predict that the slope of the Phillips curve may be a function of business cycle stage, there is no evidence to support such claims.

Table 5.5 P-values of tests for state-dependency with respect to measures of business cycle and climate

s_{kt}^j	inflation equation				output gap equation				interest rate equation			
	Maximum power $J = 3$		Maximum power $J = 4$		Maximum power $J = 3$		Maximum power $J = 4$		Maximum power $J = 3$		Maximum power $J = 4$	
	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2
cu_t	0.268	0.213	0.532	0.424	0.030	0.030	0.044	0.044	0.000	0.001	0.001	0.003
ai_ma_t	0.099	0.083	0.097	0.084	0.001	0.002	0.001	0.003	0.005	0.007	0.014	0.018
ai_di_t	0.201	0.160	0.295	0.230	0.002	0.003	0.000	0.001	0.014	0.016	0.026	0.029
cs_t	0.119	0.098	0.152	0.123	0.006	0.008	0.031	0.033	0.010	0.012	0.007	0.011

5.3.2 State-dependency with respect to measures of labour market conditions

Labour market conditions play a fundamental role in *downward wage rigidity models* which suggest that the slope of the Phillips curve is flatter when the labour market is in the doldrums. Some implicit relations also exist between the shape of the labour market and models of *consumers' behaviour* and the concept of *procyclical elasticity of demand* because the consumers' purchasing power crucially depends on the situation on the labour market. By the same token, labour market conditions influence the consumers' reference point which is critical for the shape of the IS curve according to the *cumulative prospect theory*. Since the Federal Reserve's dual mandate obliges central bankers to achieve full employment, one may also expect that the standing of the labour market may result in state-dependency of the Taylor rule, especially if central bankers have *asymmetric preferences* or are proponents of *the opportunistic approach to disinflation*.

The state-dependency is tested with respect to four measures of the labour market conditions as listed in Table 5.6 (see Appendix A.5 for a detailed description of the data).

Table 5.6 The selected measures of labour market conditions

Tag	Short description
ur_t	Civilian unemployment rate
$w\&s_t$	Compensation of employees: wages and salaries, annualised percent change from quarter ago
$lfpr_t$	Civilian labour force participation rate
$lmci_t$	Labour Market Conditions Index

The outcomes (see Table 5.7) are sensitive to the selection of the 'state' variable but robust with respect to the choice of the maximum power ($J = 3$ or $J = 4$) and the test statistic (F or χ^2). The most robust evidence for state-dependency is found in the case of the output gap and interest rate equations with respect to the overall index of labour market conditions. At the same time, the dynamics of wages and salaries influence the shape of the inflation and output gap equations, although in the latter case the results are sensitive whether $J = 3$ or $J = 4$. The detected state-dependency of the inflation equation with respect to the dynamics of wages and salaries may be perceived as consistent with the existence of *downward wage rigidity*.

Table 5.7 P-values of tests for state-dependency with respect to measures of labour market conditions

s_{kt}^{j}	inflation equation				output gap equation				interest rate equation			
	Maximum power $J = 3$		Maximum power $J = 4$		Maximum power $J = 3$		Maximum power $J = 4$		Maximum power $J = 3$		Maximum power $J = 4$	
	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2
ur_t	0.208	0.166	0.471	0.371	0.526	0.434	0.678	0.563	0.802	0.720	0.583	0.471
$w\&s_t$	0.011	0.013	0.025	0.029	0.031	0.031	0.068	0.062	0.218	0.173	0.356	0.277
$lfpr_t$	0.082	0.070	0.152	0.123	0.146	0.118	0.167	0.134	0.445	0.361	0.339	0.263
$lmci_t$	0.670	0.575	0.835	0.739	0.003	0.005	0.001	0.002	0.002	0.004	0.001	0.004

5.3.3 State-dependency with respect to measures of financial conditions

Although the general premises behind state-dependency which were discussed in section 2 predict no explicit relation between financial conditions and the shape of the Phillips curve, one may argue that implicit links are existent; for example, the enterprises' ability to invest in production capacity (*capacity constraint* models) may be seriously restrained by the current financial climate in the economy. Similarly, financial conditions may influence the pricing behaviour of enterprises via effects on barriers to enter the market, which play an important role in models of the *firms' strategic behaviour in an imperfectly competitive environment* (e.g. *limit pricing as entry deterrent* or *procyclical competitiveness*). On the contrary, there is no doubt that the financial conditions are crucial for the shape of the IS curve – the concepts of *flight to quality or liquidity* and the *credit channel* theory find the situation on the financial market to be crucial for the slope of the IS curve. As far as the Taylor rule is concerned, financial conditions may be important when the *zero lower bound* is close to be binding or when the central bank uses its verbal power to influence the dynamics of some financial indicators via the expectations channel (e.g. providing the financial market with *forward guidance*). Moreover, conducting the *robust policy* in the presence of the *models' parameter uncertainty* may require analysing the behaviour of many financial indicators; for example, a typical assumption of complete or at least constant pass-through between the federal funds rate and the interest rate faced by enterprises can (sometimes) be violated. Then the interest rate rule may exhibit state-dependency with respect to the shape of the financial market where the pass-through takes place.

To supplement the above considerations, it is important to note that state-dependency with respect to measures of financial conditions (the general premises behind state-dependency) might hardly be distinguishable from state-dependency with respect to measures of financial development and the Greenspan standard of conducting the monetary policy (premises behind state-dependency which are specific to the Greenspan era).

Since there are many indicators which may serve as variables describing the financial conditions, we grouped them into four main subcategories: financial conditions indices and subindices, monetary aggregates, interest rate quality spreads and indicators of the credit portfolio. The selected variables are listed in Table 5.8, in which the dashed line separates the aforementioned subgroups (see Appendix A.5 for a detailed description of the data).

Table 5.8 The selected measures of financial conditions

Tag	Short description
	Indices of financial conditions
$ccdi_t$	CredAbility Consumer Distress Index[57]
$fcnls_t$	Chicago Fed National Financial Conditions Nonfinancial Leveral Subindex
$fcls_t$	Chicago Fed National Financial Conditions Leverage Subindex
$fccs_t$	Chicago Fed National Financial Conditions Credit Subindex
$fcrs_t$	Chicago Fed National Financial Conditions Risk Subindex
$afci_t$	Chicago Fed Adjusted National Financial Conditions Index
fci_t	Chicago Fed National Financial Conditions Index
	Monetary aggregates
mb_t	Board of governors monetary base, annualised percent change from quarter ago
mb_gdp_t	Board of governors monetary base to gross domestic product (nominal ratio)
mzm_t	MZM (money zero maturity) stock, annualised percent change from quarter ago
$m2_t$	M2 money stock, annualised percent change from quarter ago
	Interest rate quality spreads
baa_i_t	Moody's seasoned Baa corporate bond minus federal funds rate
aaa_i_t	Moody's seasoned Aaa corporate bond minus federal funds rate
	Quality of credit portfolio
llr_tl_t	Loan loss reserve to total loans for all U.S. banks
fat_t	Number of failures and assistance transactions of all institutions for the United States
nl_tl_t	Nonperforming loans to total loans for all U.S. banks
dr_t	Delinquency rate on all loans
cor_t	Charge-off rate on all loans

The results of the state-dependency tests (see Table 5.9) are highly sensitive to the choice of potential ‘state’ variable. Among the investigated variables, the CredAbility Consumer Distress Index[57], nonperforming loans to total loans ratio and delinquency rate on all loans are the only variables which are found to be significant for all of the equations. On the contrary, the Chicago Fed National Financial Conditions Index and Moody’s seasoned Baa corporate bond minus federal funds rate are the only variables which are insignificant in the performed tests for all of the equations no matter what the choice of J (3 or 4) and test statistic (F or χ^2)

[57] ‘CredAbility Consumer Distress Index’ is a name invented by ClearPoint Credit Counseling Solutions (formerly CredAbility) – see www.credability.org.

is. As far as distinguished subgroups are concerned, the interest rate quality spreads are found to be irrelevant for all of the equations. In the case of the other three groups, for every equation at least three variables from each group are found to be significant ‘state’ variables. Overall, out of the 72 test statistics for every equation, 30, 28 and 34 are significant for the inflation, output gap, and interest rate equations, respectively.

Table 5.9 P-values of tests for state-dependency with respect to measures of financial conditions

s_{kt}^{j}	inflation equation				output gap equation				interest rate equation			
	Maximum power $J = 3$		Maximum power $J = 4$		Maximum power $J = 3$		Maximum power $J = 4$		Maximum power $J = 3$		Maximum power $J = 4$	
	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2
Indices of financial conditions												
$ccdi_t$	0.004	0.006	0.062	0.058	0.017	0.018	0.018	0.022	0.006	0.008	0.019	0.023
$fcnls_t$	0.732	0.642	0.035	0.037	0.507	0.417	0.078	0.070	0.012	0.014	0.018	0.023
$fcls_t$	0.615	0.520	0.516	0.410	0.000	0.000	0.000	0.001	0.036	0.034	0.037	0.039
$fccs_t$	0.012	0.014	0.038	0.039	0.003	0.005	0.005	0.009	0.205	0.163	0.064	0.059
$fcrs_t$	0.033	0.032	0.006	0.010	0.207	0.165	0.493	0.390	0.420	0.339	0.179	0.143
$afci_t$	0.001	0.003	0.003	0.006	0.223	0.177	0.284	0.221	0.013	0.015	0.002	0.005
fci_t	0.616	0.520	0.367	0.286	0.089	0.075	0.072	0.065	0.716	0.624	0.293	0.228
Monetary aggregates												
mb_t	0.040	0.038	0.168	0.135	0.000	0.000	0.000	0.002	0.737	0.646	0.538	0.430
mb_gdp_t	0.454	0.369	0.152	0.124	0.318	0.253	0.535	0.427	0.116	0.096	0.058	0.054
mzm_t	0.593	0.498	0.531	0.423	0.060	0.053	0.148	0.121	0.002	0.003	0.015	0.019
$m2_t$	0.641	0.546	0.655	0.540	0.451	0.366	0.430	0.337	0.002	0.004	0.000	0.000
Interest rate quality spreads												
baa_i_t	0.488	0.399	0.755	0.644	0.075	0.064	0.222	0.175	0.610	0.515	0.553	0.443
aaa_i_t	0.371	0.297	0.702	0.588	0.276	0.219	0.546	0.436	0.583	0.488	0.340	0.265
Quality of credit portfolio												
llr_tl_t	0.325	0.259	0.202	0.160	0.108	0.090	0.309	0.240	0.024	0.025	0.103	0.088
fat_t	0.000	0.000	0.000	0.000	0.423	0.342	0.483	0.381	0.298	0.237	0.454	0.357
nl_tl_t	0.000	0.000	0.000	0.000	0.011	0.013	0.038	0.039	0.024	0.025	0.010	0.015
dr_t	0.000	0.000	0.000	0.000	0.001	0.002	0.006	0.010	0.013	0.015	0.004	0.008
cor_t	0.185	0.148	0.062	0.058	0.031	0.030	0.006	0.010	0.137	0.111	0.276	0.215

5.3.4 State-dependency with respect to measures of uncertainty

Rational inattention models predict that economic agents pay relatively more attention to more volatile shocks. Then what matters for the slope of the Phillips curve is not the absolute but rather the relative uncertainty of inflation. In consequence, more general measures of uncertainty may also influence the shape of the Phillips curve. According to *Bloom’s concept of the role of uncertainty shocks* (Bloom 2009), increased uncertainty makes economic agents temporarily irresponsive to other shocks, but when uncertainty eases the impulses are propagated more strongly with some lag. As a result, the slope of the IS curve should be a function of uncertainty. Since uncertainty is also one of the fundamental factors driving sentiment on the financial market and its pricing mechanism, one may also expect that measures of uncertainty should affect the shape of the IS curve via the *credit channel* and *flight to quality* and *liquidity*. Uncertainty about the level of economic activity (or other variables of interest), by analogy to *Bloom's concept of the role of uncertainty shocks* (Bloom 2009), may influence the central bankers' responsiveness to inflation and output gaps, thus making the Taylor rule state-dependent.

Finally, it is also worth recalling Bloom's (2009) finding that periods of increased uncertainty often correspond with economic and financial crises (see paragraph 3.5.2.). Then the effects of uncertainty and crises might be difficult to tell apart.

We test for state-dependency of the monetary transmission mechanism with respect to two measures of uncertainty as were developed by Baker, Bloom and Davis (2013) (see Table 5.10).

Table 5.10 The selected measures of uncertainty

Tag	Short description
$epui_t$	Economic Policy Uncertainty Index for United States by Baker, Bloom and Davis (2013)
$emeui_t$	Equity Market-related Economic Uncertainty Index by Baker, Bloom and Davis (2013)

The results we obtain (see Table 5.11) show that the output gap and the interest rate equations exhibit state-dependency with respect to both measures of uncertainty (with some sensitivity to the choice of J), while no such relation is detected for the inflation equation.

Table 5.11 P-values of tests for state-dependency with respect to measures of uncertainty

s_{kt}^{j}	inflation equation				output gap equation				interest rate equation			
	Maximum power $J=3$		Maximum power $J=4$		Maximum power $J=3$		Maximum power $J=4$		Maximum power $J=3$		Maximum power $J=4$	
	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2
$epui_t$	0.331	0.264	0.533	0.425	0.003	0.005	0.007	0.011	0.043	0.040	0.118	0.099
$emeui_t$	0.383	0.307	0.304	0.236	0.082	0.069	0.048	0.047	0.007	0.010	0.011	0.016

5.3.5 State-dependency with respect to measures of globalisation

As was discussed in subsection 3.3, globalisation may be an important factor standing behind the flattening of the Phillips curve in the Greenspan era (especially when compared to earlier Fed presidencies). On the other hand, there was only little theoretical and empirical support for the hypothesis that globalisation may affect the shape of the IS curve. As far as the Taylor rule is concerned, the impact of globalisation was discussed to operate through at least three channels – one reinforces the problems of uncertainty while the other two call for modifications in the monetary policy strategy.

The selected potential 'state' variables were divided into two subgroups corresponding to world and U.S. economies, respectively (see Table 5.12 for a short and Appendix A.5 for a detailed description of the data). Similarly as before, the dashed line separates the two groups.

Table 5.12 The selected measures of globalisation

Tag	Short description
	World data
$wgdp_t$	World gross domestic product, constant 2005 dollar, annualised percent change from quarter ago
ws_gdp_t	World gross savings, percent of world gross domestic product (nominal ratio)
wds_gdp_t	World gross domestic savings, percent of world gross domestic product (nominal ratio)
we_gdp_t	World exports of goods and services, percent of world gross domestic product, (nominal ratio)
	U.S. data
e_gdp_t	Real exports of goods and services, percent of real gross domestic product (real ratio)
i_gdp_t	Real imports exports of goods and services, percent of real gross domestic product (real ratio)
ca_gdp_t	Balance on current account, percent of gross domestic product (nominal ratio)
aa_gdp_t	U.S. assets abroad, percent of gross domestic product (nominal ratio)
fa_gdp_t	Foreign assets in the U.S., percent of gross domestic product (nominal ratio)
usd_t	Trade weighted U.S. dollar index, annualised percent change from quarter ago

Table 5.13 P-values of tests for state-dependency with respect to measures of globalisation

s_{kt}^{j}	inflation equation				output gap equation				interest rate equation			
	Maximum power $J=3$		Maximum power $J=4$		Maximum power $J=3$		Maximum power $J=4$		Maximum power $J=3$		Maximum power $J=4$	
	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2
						World data						
$wgdp_t$	0.089	0.075	0.081	0.072	0.053	0.048	0.107	0.091	0.019	0.020	0.086	0.075
ws_gdp_t	0.046	0.043	0.086	0.076	0.048	0.043	0.064	0.059	0.422	0.341	0.088	0.077
wds_gdp_t	0.059	0.052	0.114	0.096	0.072	0.062	0.064	0.059	0.414	0.334	0.617	0.503
we_gdp_t	0.417	0.336	0.652	0.537	0.053	0.047	0.049	0.048	0.048	0.044	0.116	0.098
						U.S. data						
e_gdp_t	0.052	0.047	0.105	0.090	0.209	0.166	0.264	0.206	0.035	0.034	0.159	0.129
i_gdp_t	0.170	0.137	0.392	0.305	0.095	0.080	0.084	0.074	0.120	0.099	0.115	0.096
ca_gdp_t	0.000	0.001	0.000	0.002	0.000	0.001	0.001	0.003	0.439	0.356	0.275	0.214
aa_gdp_t	0.060	0.053	0.112	0.095	0.069	0.060	0.114	0.096	0.667	0.572	0.867	0.780
fa_gdp_t	0.140	0.113	0.127	0.105	0.225	0.179	0.159	0.129	0.640	0.545	0.661	0.546
usd_t	0.265	0.211	0.384	0.299	0.753	0.664	0.765	0.656	0.411	0.331	0.310	0.241

In the case of variables describing the world economy, the results of the state-dependency tests (see Table 5.13) are highly sensitive to the choice of 'state' variable, J (3 or 4) or test statistic (F or χ^2). The most robust detection of state-dependency is reported for the inflation and output gap equations with respect to the balance on the current account expressed as a percentage of the GDP.

5.3.6 State-dependency with respect to measures of composition of the economy

Among the many structural changes of the U.S. economy which were discussed in subsection 3.4, we distinguished a pure composition effect. We argued that since the slopes of sectoral Phillips and IS curves may substantially vary among different sectors, the slopes of the aggregate Phillips and IS curve should follow the evolution of the economy's composition. Such an environment should induce the monetary authorities to adjust their policy in line with the observed changes. Structural changes may also be perceived as an additional source of uncertainty due to problems with estimating the permanent and transitory components in real time. In consequence, one may expect that the changing composition of the economy should exert some influence on the shape of the Taylor rule.

We propose to test state-dependency with respect to two simple measures of composition of the economy as listed in Table 5.14 (see Appendix A.5 for a detailed description of the data).

Table 5.14 The selected measures of composition of the economy

Tag	Short description
$lshare_t$	Labour share in nonfarm business sector
sva_gdp_t	Services: value added: percent of gross domestic product (nominal ratio)

We find that none of the selected variables is significant for the inflation equation, while both variables are significant for the output gap equation (see Table 5.15). The interest rate equation exhibits significant state-dependency only with respect to labour share, but the results are sensitive to the choice of J.

Table 5.15. P-values of tests for state-dependency with respect to measures of composition of the economy

s_{kt}^{j}	inflation equation				output gap equation				interest rate equation			
	Maximum power $J = 3$		Maximum power $J = 4$		Maximum power $J = 3$		Maximum power $J = 4$		Maximum power $J = 3$		Maximum power $J = 4$	
	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2
$lshare_t$	0.125	0.102	0.321	0.250	0.008	0.010	0.019	0.023	0.001	0.002	0.001	0.003
sva_gdp_t	0.183	0.146	0.154	0.125	0.003	0.005	0.011	0.016	0.399	0.321	0.340	0.265

5.3.7 State-dependency with respect to measures of potential growth and development

In subsection 3.4 we argued that rapid development of information and computer technology was potent to influence the shape of the Phillips curve through many potential channels (e.g. via lowering the costs of price changes and logistics or facilitating price comparisons and forecasts but increasing uncertainty). At the same time, the influence of the rapid development of ICT on the IS curve seemed to be operating mainly through better access to information and forecasts and increased uncertainty related to the ongoing structural changes.[58] As we emphasised in the previous paragraph and in paragraph 3.4.3, the same channels could also influence the Taylor rule.

Here we test for state-dependency with respect to variables which might be seen as proxies of the effects of ICT development rather than the ICT development itself. It is also worth noting that the selected variables cover a broader set of processes that might have boosted technological progress. Naturally, such a choice of 'state' variables is partially imposed by data availability, but we also argue that ICT development was a prerequisite for progress in many other closely related areas (e.g. development of financial services and innovations and the emergence of knowledge economy). Since such processes are prolonged in time, using the potential GDP, R&D or number of patents applications as transition variables seems to be a sensible choice (see Table 5.16 for a short and Appendix A.5 for a detailed description of the data).

Table 5.16 The selected measures of potential growth and development

Tag	Short description
gdp_pot_t	Real potential gross domestic product, chained 2009 dollars, annualised percent change from quarter ago
rd_gdp_t	Real gross domestic product: research and development, percent of real gross domestic product, chained 2009 dollars (real ratio)
rd_t	Gross domestic product: research and development, chained 2009 dollars, annualised percent change from quarter ago
pa_r_t	Patent applications, residents, annualised percent change from quarter ago
pa_rn_t	Patent applications, residents + nonresidents, annualised percent change from quarter ago

The test results (see Table 5.17) show that all three equations exhibit significant state-dependency with respect to potential growth. Moreover, research and development outlays to the GDP ratio are a source of state-dependency in the case of the inflation equation.

[58] In the next paragraph we analyse state-dependency with respect to measures of financial development, which is closely related to the development of information and computer technology.

Table 5.17 P-values of tests for state-dependency with respect to measures of potential growth and development

s_{kt}^{j}	inflation equation				output gap equation				interest rate equation			
	Maximum power $J = 3$		Maximum power $J = 4$		Maximum power $J = 3$		Maximum power $J = 4$		Maximum power $J = 3$		Maximum power $J = 4$	
	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2
gdp_pot_t	0.000	0.000	0.000	0.000	0.006	0.008	0.004	0.007	0.049	0.045	0.004	0.008
rd_gdp_t	0.000	0.000	0.000	0.000	0.307	0.244	0.490	0.387	0.144	0.117	0.257	0.201
rd_t	0.196	0.156	0.367	0.285	0.237	0.188	0.427	0.334	0.616	0.521	0.787	0.680
pa_r_t	0.494	0.405	0.761	0.652	0.784	0.700	0.612	0.498	0.773	0.687	0.628	0.513
pa_rn_t	0.638	0.543	0.859	0.769	0.344	0.274	0.597	0.484	0.302	0.240	0.219	0.173

5.3.8 State-dependency with respect to measures of financial development

Financial development is yet another manifestation of structural changes in the U.S. economy apart from the two that were considered in the last two paragraphs. As we discussed in subsection 3.4, financial innovations were potent to affect the shape of the IS curve (e.g. via eroding the monopolistic positon of the central bank as a provider of means of payment, dampening the credit channel of the monetary policy or facilitating intertemporal substitution of income and cash flows). We also argued that such structural changes may call for some important strategic and operational modification of the monetary policy framework. At the same time, however, in the literature we found no theoretical support for the financial development impact on the shape of the Phillips curve.

Table 5.18 The selected measures of financial development of the economy

Tag	Short description
	Money supply to GDP ratios
mzm_gdp_t	MZM (money zero maturity) stock to gross domestic product (nominal ratio)
$m2\_gdp_t$	M2 money stock to gross domestic product (nominal ratio)
	Bank assets ratios
ta_gdp_t	Total assets at all commercial banks, percent of gross domestic product (nominal ratio)
bc_gdp_t	Bank credit at all commercial banks, percent of gross domestic product (nominal ratio)
bc_d_t	Bank credit at all commercial banks, percent of deposits of all commercial banks
cl_gdp_t	Consumer loans at all commercial banks, percent of gross domestic product (nominal ratio)
rel_gdp_t	Real estate loans at all commercial banks, percent of gross domestic product (nominal ratio)
tas_ta_t	Treasury and agency securities at all commercial banks, percent of total assets of all commercial banks
ltd_d_t	Large time deposits at all commercial banks, percent of deposits of all commercial banks
nfb_cb_t	Total assets of nonfinancial corporate business, percent of total assets of all commercial banks
	Other measures
mf_gdp_t	Money market mutual funds: total financial assets, percent of gross domestic product (nominal ratio)
nim_t	Net interest margin for all U.S. banks
roa_t	Return on average assets for all U.S. banks
$stck\_gdp_t$	Wilshire 5000 Full Cap Price Index©, percent of gross domestic product (nominal ratio)

Similarly as in the previous paragraph, we test for state-dependency with respect to variables which might be seen as proxies of some effects of financial development rather than the financial development itself. In particular, we use a broad set of variables which may be perceived as measures of financialisation of the economy, i.e. money supply to GDP ratios and various bank asset ratios (see Table 5.18 for a short and Appendix A.5 for a detailed description of the data).

Surprisingly, despite the lack of strong theoretical support, we find that the inflation equation is state-dependent with respect to the largest number of selected transition variables (9 out of 14) (see Table 5.19). On the other hand, the output gap and interest rate equations are found to be state-dependent with respect to only 3 out of 14 variables, although there was strong theoretical justification suggesting state-dependency of the IS curve. Moreover, one detection is sensitive to the choice of J (3 or 4).

Table 5.19 P-values of tests for state-dependency with respect to measures of financial development of the economy

s_{kt}^{j}	inflation equation				output gap equation				interest rate equation			
	Maximum power $J=3$		Maximum power $J=4$		Maximum power $J=3$		Maximum power $J=4$		Maximum power $J=3$		Maximum power $J=4$	
	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2
Money supply to GDP ratios												
mzm_gdp_t	0.000	0.000	0.000	0.000	0.001	0.002	0.000	0.002	0.161	0.130	0.202	0.160
$m2\_gdp_t$	0.000	0.000	0.000	0.000	0.608	0.513	0.798	0.694	0.607	0.512	0.486	0.384
Bank assets ratios												
ta_gdp_t	0.001	0.002	0.004	0.008	0.653	0.557	0.825	0.727	0.628	0.532	0.186	0.148
bc_gdp_t	0.008	0.010	0.032	0.034	0.755	0.667	0.838	0.742	0.626	0.530	0.301	0.235
bc_d_t	0.000	0.000	0.000	0.000	0.421	0.340	0.458	0.360	0.222	0.177	0.227	0.179
cl_gdp_t	0.920	0.871	0.733	0.621	0.088	0.074	0.033	0.035	0.540	0.447	0.582	0.470
rel_gdp_t	0.000	0.000	0.000	0.000	0.148	0.120	0.113	0.095	0.505	0.415	0.187	0.149
tas_ta_t	0.087	0.074	0.182	0.145	0.298	0.237	0.100	0.086	0.116	0.095	0.140	0.115
ltd_d_t	0.001	0.002	0.002	0.006	0.582	0.488	0.382	0.297	0.246	0.195	0.283	0.221
nfb_cb_t	0.235	0.187	0.180	0.144	0.158	0.128	0.279	0.218	0.088	0.074	0.041	0.041
Other measures												
mf_gdp_t	0.294	0.234	0.401	0.313	0.000	0.000	0.000	0.000	0.003	0.004	0.007	0.012
nim_t	0.009	0.011	0.000	0.002	0.064	0.056	0.148	0.121	0.172	0.138	0.188	0.150
roa_t	0.061	0.054	0.042	0.043	0.519	0.428	0.233	0.183	0.087	0.074	0.098	0.085
$stck\_gdp_t$	0.001	0.002	0.002	0.004	0.350	0.280	0.514	0.408	0.267	0.212	0.194	0.154

5.3.9 State-dependency with respect to variables related to the ‘Greenspan conundrum’

As we argued in paragraph 3.5, flight to quality in an international dimension combined with the global saving glut is potent to affect the central bank’s leverage over long-term interest rates with the use of the short-term rate. It is plausible that such a situation may influence the shape of the monetary transmission mechanism, i.e. affect the parameters of the Phillips and IS curves. Failure to control long-term interest rates could also induce the monetary authorities to adjust their monetary rule.

We propose to test state-dependency with respect to variables related to the 'Greenspan conundrum', i.e. to measures of spreads between the long- and short-term interest rate (see Table 5.20 for a short and Appendix A.5 for a detailed description of the data).

Table 5.20 The selected variables related to 'Greenspan conundrum'

Tag	Short description
$t10y\_3m_t$	10-year treasury constant maturity rate minus 3-month treasury constant maturity rate
$t10y\_ffr_t$	10-year treasury constant maturity rate minus federal funds rate

According to the tests (see Table 5.21) performed here, none of the selected variables has a statistically significant influence on the inflation and output gap equation, while both variables exert such an influence on the interest rate equation.

Table 5.21 P-values of tests for state-dependency with respect to variables related to 'Greenspan conundrum'

s_{kt}^{j}	inflation equation				output gap equation				interest rate equation			
	Maximum power $J = 3$		Maximum power $J = 4$		Maximum power $J = 3$		Maximum power $J = 4$		Maximum power $J = 3$		Maximum power $J = 4$	
	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2
$t10y\_3m_t$	0.438	0.355	0.669	0.554	0.608	0.513	0.847	0.754	0.005	0.008	0.025	0.029
$t10y\_ffr_t$	0.807	0.726	0.635	0.520	0.357	0.286	0.394	0.307	0.000	0.000	0.000	0.000

5.3.10 State-dependency with respect to variables related to some aspects of the Greenspan standard

In subsection 3.6 we tried to find potential sources of state-dependency in the Greenspan standard, i.e. the way Greenspan conducted the monetary policy. We found that Greenspan was known to be a proponent of pre-emptive actions against very low probable but also very adverse events, and he followed the principle of 'don't try to burst bubbles; mop up after'. Obviously, such features of the Greenspan standard should result in state-dependency of the Taylor rule with respect to the dynamics of some assets' prices. Since the 'Greenspan put' (the implicit put option against large asset price drops) could have been taken into account by economic agents, one may also expect that this element of the Greenspan standard was potent to influence the shapes of the Phillips and IS curves (especially those of the latter due to its relation to the financial market via interest rate and investment-saving decision-making process).

We propose to test for state-dependency with respect to the dynamics of three groups of assets: stock exchange indices, real estate and commodities.[59] As previously, the groups are separated with a dashed line in Table 5.22 (see Appendix A.5 for a detailed description of the data).

Table 5.22 The selected measures of variables related to some aspects of Greenspan standard

Tag	Short description
	Stock prices
$sp500_t$	S&P 500©, annualised percent change from quarter ago
$nasd_t$	NASDAQ Composite Index©, annualised percent change from quarter ago
$wilsh_t$	Wilshire 5000 Full Cap Price Index©, annualised percent change from quarter ago
djc_t	Dow Jones Composite©, annualised percent change from quarter ago
$djia_t$	Dow Jones Industrial Average©, annualised percent change from quarter ago
$nasd100_t$	NASDAQ 100©, index, annualised percent change from quarter ago
	Real estate prices
$spcs_t$	S&P/Case-Shiller U.S. National Home Price Index©, annualised percent change from quarter ago
hpi_t	All-transactions house price index by U.S. Federal Housing Finance Agency, annualised percent change from quarter ago
	Commodity prices
wti_t	Spot oil price: West Texas Intermediate©, dollars per barrel, annualised percent change from quarter ago
cpe_t	World Bank commodity price data: energy, annualised percent change from quarter ago
$cpne_t$	World Bank commodity price data: nonenergy, annualised percent change from quarter ago

We find (see Table 5.23) that the dynamics of stock indices have no effect on the interest rate equation and virtually no effect on the shape of the inflation equation, while they exert a significant influence on the output gap equation. Surprisingly, although all of the selected indices are highly collinear and measure a similar underlying economic process (i.e. dynamic of the stock exchange), the results are sensitive to the choice of index. The dynamics of prices of real estate are found to influence only the interest rate equation and only when the S&P/Case-Shiller U.S. National Home Price Index© is a transition variable. As far as commodity prices are concerned, we find that oil prices are important for the interest rate equation. There is also some evidence that energy commodity prices are an important source of state-dependency of the inflation and the output gap equations but the outcomes are

[59] We do not take debt market assets into account, since their dynamic is related to the 'Greenspan conundrum' rather than the Greenspan standard – Blinder and Reis (2005) abstracted from prices on the domestic debt market in their analysis of the Greenspan standard.

sensitive to the choice of test statistic and J. At the same time, non-energy commodity prices seem to be irrelevant to the shape of all three equations.

Table 5.23 P-values of tests for state-dependency with respect to variables related to some aspects of Greenspan standard

s_{kt}^j	inflation equation				output gap equation				interest rate equation			
	Maximum power $J=3$		Maximum power $J=4$		Maximum power $J=3$		Maximum power $J=4$		Maximum power $J=3$		Maximum power $J=4$	
	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2
Stock prices												
$sp500_t$	0.138	0.112	0.280	0.218	0.000	0.000	0.000	0.001	0.218	0.174	0.234	0.183
$nasd_t$	0.208	0.166	0.089	0.078	0.232	0.185	0.026	0.029	0.348	0.278	0.164	0.132
$wilsh_t$	0.060	0.053	0.129	0.107	0.000	0.000	0.000	0.002	0.407	0.328	0.180	0.144
djc_t	0.783	0.698	0.627	0.512	0.010	0.012	0.057	0.054	0.167	0.134	0.270	0.211
$djia_t$	0.628	0.533	0.187	0.149	0.000	0.001	0.001	0.003	0.409	0.330	0.476	0.376
$nasd100_t$	0.082	0.070	0.040	0.041	0.043	0.040	0.084	0.074	0.098	0.082	0.112	0.095
Real estate prices												
$spcs_t$	0.544	0.451	0.448	0.351	0.123	0.100	0.299	0.232	0.008	0.010	0.048	0.047
hpi_t	0.551	0.457	0.548	0.439	0.165	0.133	0.122	0.102	0.229	0.182	0.406	0.317
Commodity prices												
wti_t	0.194	0.155	0.207	0.164	0.722	0.631	0.290	0.226	0.005	0.007	0.011	0.016
cpe_t	0.053	0.048	0.163	0.131	0.310	0.247	0.010	0.015	0.058	0.051	0.063	0.058
$cpme_t$	0.610	0.515	0.670	0.555	0.782	0.697	0.712	0.598	0.250	0.198	0.326	0.253

5.4 Summary

In this section we showed that linearity and state-independency of the monetary transmission mechanism is a questionable assumption. Less euphemistically, the null hypotheses of linearity and state-independency of the baseline model of the monetary transmission mechanism were broadly rejected by the tests performed here despite the conservative approach to testing which was based on LM-type tests.

The results were particularly strong in the case of state-dependency of the output gap equation (see Table 5.24), which contrasts with the fact that the problem of state-dependency of the IS curve does not receive too much attention in the literature. Conversely, the literature is focused on nonlinearity of the Phillips curve and the Taylor rule while in these cases our results were the weakest. It also seems that in the case of some sources of state-dependency which were found important for particular equations (e.g. financial development for the inflation equation) the theoretical predictions suggested by the literature are rather implicit than explicit. On the one hand this may signal some promising area for a theoretical research, while on the other hand this also calls us to substantiate our findings with more detailed empirical results. Therefore in the following section we move on to econometric modelling of the nonlinearity and state-dependency of the monetary transmission mechanism.

Table 5.24 Percentage of rejections of hypothesis of linearity and state-independency

	inflation equation	output gap equation	interest rate equation	overall
nonlinearity*	11%	22%	18%	17%
state-dependency	31%	38%	33%	34%
business cycle and climate	0%	100%	100%	67%
labour market conditions	25%	38%	25%	29%
financial conditions	42%	39%	47%	43%
- indices of financial conditions	57%	43%	57%	52%
- monetary aggregates	13%	25%	50%	29%
- interest rate quality spreads	0%	0%	0%	0%
- quality of credit portfolio	60%	60%	50%	57%
uncertainty	0%	75%	75%	50%
globalisation	18%	25%	15%	19%
- world data	13%	38%	25%	25%
- U.S. data	21%	17%	8%	15%
composition of the economy	0%	100%	50%	50%
potential growth and development	40%	20%	20%	27%
financial development	68%	18%	11%	32%
- money supply to GDP ratios	100%	50%	0%	50%
- bank assets ratios	63%	6%	6%	25%
- other measures	63%	25%	25%	38%
Greenspan conundrum	0%	0%	100%	33%
Greenspan standard	7%	45%	18%	23%
- stock prices	8%	75%	0%	28%
- real estate prices	0%	0%	50%	17%
- commodity prices	8%	17%	33%	19%

* including indirect nonlinearity

linearity state-independency	0%	(0%, 20%]	(20%, 40%]	(40%, 60%]	(60%, 80%]	(80%, 100%]	nonlinearity state-dependency

6. Modelling nonlinearity and state-dependency of the monetary transmission mechanism

6.1 Introduction

As was mentioned before, in this section we deal with the process of econometric modelling of nonlinearity and state-dependency of the monetary transmission mechanism. At the very beginning we shortly analyse the adopted approach, which is based on smooth transition autoregressive ($STAR$) models, and only later do we discuss the results of estimation and evaluation of the $STAR$ models.

6.2 Overview of the $\boldsymbol{STAR}$ framework

Before proceeding to the results of the modelling exercise, we find it useful to present some basic information on the $STAR$ framework and justify our choice. Although the beginning of $STAR$ models dates back to the 1970s and 1980s, it was Teräsvirta (1994) who put in order some of the dispersed motifs into a more general theory and modelling strategy of $STAR$ models.[60] Since then many modifications and developments have been proposed and neither a unified nor indisputable $STAR$ methodology has been coined yet. Therefore, many aspects of the modelling procedure are subjected to the econometrician's choice. The following paragraphs should shed some light on the adopted modelling strategy and on the arguments behind our choice.

6.2.1 Concept of $\boldsymbol{STAR}$ models

The standard smooth transition regression (STR) model is an additive nonlinear model that can be perceived as a switching regression model with two regimes and an observable switching variable s_t:

$$y_t = \boldsymbol{\varphi}'\boldsymbol{z}_t + \boldsymbol{\psi}'\boldsymbol{z}_t G(s_t;\gamma,\boldsymbol{c}) + \varepsilon_t \qquad G(s_t;\gamma,\boldsymbol{c}) \in [0;1] \qquad (6.1)$$

[60] See Teräsvirta, Tjøstheim and Granger (2010, Ch. 16.3.1) for a historical note.

If $\boldsymbol{z}_t$ contains lagged values of the dependent variable y_t, the model is usually called a smooth transition autoregressive ($STAR$) model. The equation (6.1) reveals that the $ST(A)R$ model is actually a weighted average of two linear models and that the relative weight assigned to each of the two linear models depends on the value of the transition function $G(s_t;\gamma,\boldsymbol{c})$, where γ is the smoothing parameter, $\boldsymbol{c}=(c_1,\dots,c_K)'$ are the location parameters, and $G(s_t;\gamma,\boldsymbol{c})$ is continuous with respect to transition (or switching) variable s_t in the parameter space. Although the catalogue of transition functions is potentially infinite, the transition function $G(s_t;\gamma,\boldsymbol{c})$ typically takes one of the three following forms:

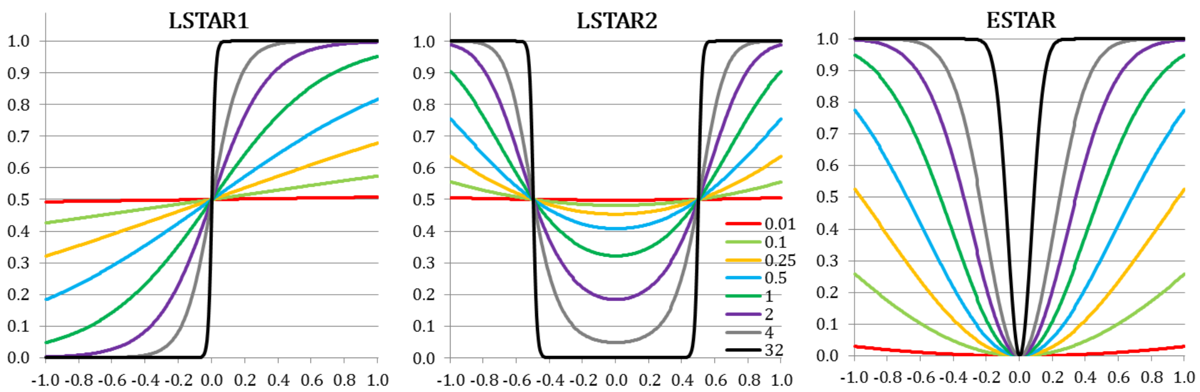
$$G(s_t;\gamma,\boldsymbol{c}) = (1+\exp\{-\gamma(s_t-c)\})^{-1} \qquad \gamma>0 \qquad (6.2)$$

$$G(s_t;\gamma,\boldsymbol{c}) = (1+\exp\{-\gamma(s_t-c_1)(s_t-c_2)\})^{-1} \qquad c_1<c_2, \gamma>0 \qquad (6.3)$$

$$G(s_t;\gamma,\boldsymbol{c}) = 1-\exp\{-\gamma(s_t-c)^2\} \qquad \gamma>0 \qquad (6.4)$$

The transition functions (6.2), (6.3), and (6.4) correspond with the $LSTAR1$, $LSTAR2$ and $ESTAR$ models, respectively, where L stands for logistic and E for exponential, while 1 and 2 denote the number of location parameters c_k in the $LSTAR$ models. Figure 6.1 presents the difference among the defined transition functions depending on the value of the smooth parameter γ.

Figure 6.1 The plot of $G(s_t;\gamma,\boldsymbol{c})$ for $LSTAR1$ ($c=0$), $LSTAR2$ ($c_1=-0.5$, $c_2=0.5$) and $ESTAR$ ($c=0$) specifications, depending on the value of the smooth parameter γ (the value of s_t on X-axis)



Intuitively, the $LSTAR1$ model is adequate when model behaviour differs for small and large values of s_t (e.g. inflation dynamics varies between low and high inflation or capacity utilisation regimes), while $LSTAR2$ and $ESTAR$ are more appropriate when model behaviour is different for moderate and extreme values of s_t but similar at both extremes of s_t (e.g.

inflation dynamics is similar in deflation and high inflation regimes but different when the inflation is at low levels). Such properties make the $STAR$ framework a good choice when looking for various types of asymmetries (see definition 3 in subsection 1.6).

From the econometric perspective the $STAR$ framework may be perceived as a framework which brings together the pros and alleviates the cons of threshold regression and the Markov-switching regression models. The switching variable is observable (can be controlled by an econometrician) and the transition is smooth at the same time, which means that there is no trade-off between the two features. What is more, $STAR$ models are quite parsimonious (e.g. when compared to polynomial models) and nest a linear model as a special case which is not a property held by many other nonlinear models (e.g. min-max and nonparametric models).

According to Teräsvirta, Tjøstheim and Granger (2010, Ch. 16.3.1), the $STAR$ modelling strategy consists of three stages: specification, estimation and evaluation. However, since the first two stages greatly overlap and the procedure of modelling is iterative until a satisfactory model is found, we propose to modify the strategy and to follow more legible and non-overlapping steps of modelling, i.e. preliminary specification, estimation, model selection and evaluation. The main advantage of the proposed solution is that the catalogue of plausible model specifications is set at the beginning of the modelling exercise and the chosen model is the best one (i.e. not only a satisfactory one) among the available alternatives.[61] The following subsections are devoted to consecutive stages of such a strategy.

6.2.2 Preliminary specification

In the preliminary specification stage the baseline linear model should be tested against the $STAR$ alternative. The problem of testing is, however, complicated by the fact that the nuisance parameters γ and $\boldsymbol{c}$ are not identified under the null hypothesis of linearity (see, e.g. Teräsvirta, Tjøstheim and Granger 2010, Ch. 5.5). The recommended solution is to approximate the transition function with a Taylor expansion around the $\gamma = 0$ and to apply the LM-type test, the asymptotic properties of which are unaffected under relatively weak statistical conditions.

[61] Obviously this comes at the cost of computational time since all plausible models (i.e. not only the most plausible one) should be estimated.

In fact, the procedure of testing which was presented in paragraph 5.5.2 and used there and in subsequent paragraphs for testing linearity against nonlinearity and state-independency against state-dependency is exactly the same procedure of testing linearity against the $STAR$ alternative which was recommended by Teräsvirta, Tjøstheim and Granger (2010, Ch. 16.3.2). Whenever the null hypothesis of linearity or state-independency is rejected at a 5% significance level (for a particular value of J and choice of test statistic F or χ^2), an econometrician is permitted to take the next step and to determine the catalogue of plausible transition functions; otherwise the model should be treated as linear.

The procedure of choosing the plausible transition functions depends on whether the maximum power J in test equations (5.6) and (5.9) was set to 3, as was recommended by Teräsvirta, Tjøstheim and Granger (2010 Ch. 16.3.2), or 4, as was suggested by Escribano and Jordá (1999).

For $J = 3$, the following sequence of Wald tests should be executed:

1. H_{03}: $\bigwedge_{i=1}^{I} \theta_{ki3} = 0$ in (5.6) or $\bigwedge_{i=1}^{I} \vartheta_{ki3} = \theta_{ki3} = 0$ in (5.9)
2. $H_{02}|H_{03}$: $\bigwedge_{i=1}^{I} \theta_{ki2} = 0$ in (5.6) or $\bigwedge_{i=1}^{I} \vartheta_{ki2} = \theta_{ki2} = 0$ in (5.9)
3. $H_{01}|H_{02}$: $\bigwedge_{i=1}^{I} \theta_{ki1} = 0$ in (5.6) or $\bigwedge_{i=1}^{I} \vartheta_{ki1} = \theta_{ki1} = 0$ in (5.9)

If the p-value for H_{02} is smaller than for H_{03} and p-value for H_{02} is smaller than for H_{01}, the $LSTAR2$ or $ESTAR$ model[62] should be selected. Otherwise, one should choose the $LSTAR1$ specification.

For $J = 4$, the procedure of testing is symmetric and there are only two Wald tests which should be executed:

1. H_{02}^{*}: $\bigwedge_{i=1}^{I} \theta_{ki2} = \theta_{ki4} = 0$ in (5.6) or $\bigwedge_{i=1}^{I} \vartheta_{ki2} = \theta_{ki2} = \vartheta_{ki4} = \theta_{ki4} = 0$ in (5.9)
2. H_{01}^{*}: $\bigwedge_{i=1}^{I} \theta_{ki1} = \theta_{ki3} = 0$ in (5.6) or $\bigwedge_{i=1}^{I} \vartheta_{ki1} = \theta_{ki1} = \vartheta_{ki3} = \theta_{ki3} = 0$ in (5.9)

If the p-value for H_{02}^{*} is smaller than for H_{01}^{*}, the $LSTAR2$ or $ESTAR$ specification should be chosen; in the other case the $LSTAR1$ model is more appropriate.

Obviously, both procedures are heuristic in the sense that the overall significance level is unknown. Therefore, the results of the procedures should be treated as a recommendation rather than as a rigorous verdict as to which model should be chosen; for example, our experience in handling $STAR$ models reveals that the $LSTAR2$ or $ESTAR$ specification is

[62] The procedure gives no hint on whether the $LSTAR2$ or $ESTAR$ specification should be chosen.

suggested somewhat too often because the $LSTAR1$ model is later strongly preferred at the estimation and evaluation stage. We find that such a situation usually takes place when the majority of observations is located at only one half of the $LSTAR2$ or $ESTAR$ transition functions, i.e. when the $LSTAR1$ and $LSTAR2$ or $ESTAR$ specifications might be difficult to empirically differentiate between. Bearing in mind that fact, whenever the $LSTAR2$ or $ESTAR$ specification is suggested, we also recommend that the $LSTAR1$ model be estimated as an alternative.

In our procedure of determining the preliminary specification we continue the distinction between the results for different values of J (3 or 4) and test statistics (F or χ^2), which means that for every ‘nonlinear’ or ‘state’ transition variable we have four verdicts on the suggested preliminary specification. The model is claimed to be linear or state-independent (against nonlinearity or state-dependency) with respect to the selected transition variable if in all cases there is not enough evidence to reject the null hypothesis of linearity or state-independency (i.e. when in paragraphs 5.2.2 – 5.3.10 the p-values are higher than 5% no matter what the choice of J and test statistic is). If there is at least one suggestion for the $LSTAR1$ specification, we treat such a specification as a plausible one. We adopt an analogous rule for the $LSTAR2$ and $ESTAR$ specifications, however, by bringing the aforementioned recommendation into life we always add the $LSTAR1$ specification to the set of plausible transition functions as an alternative.

In summary, the adopted procedure of determining the catalogue of plausible preliminary specifications may end up with one of the three following conclusions:

1. The model is linear or state-independent – no $STAR$ model will be estimated.
2. Only models with the $LSTAR1$ specification will be estimated and compared against the linear baseline.
3. Models with $LSTAR1$, $LSTAR2$ and $ESTAR$ specifications will be estimated and compared against the linear baseline.

The following paragraph deals with the estimation stage of models in their preliminary functional forms, while the next paragraph reveals how the final specifications of the models were chosen.

6.2.3 Estimation

The $STAR$ models can be estimated with the use of the Nonlinear Least Squares (NLS) estimator. If the error term is normally distributed, the NLS estimation is equivalent to the Maximum Likelihood Estimation (MLE), while in the case of non-normal error the estimates may be interpreted as obtained via the Quasi-Maximum Likelihood Estimation (QMLE) (van Dijk, Teräsvirta, Franses 2002). The NLS estimator is consistent under various types of regularity conditions which are 'expected to hold quite generally in practice' (Mittelhammer, Judge and Miller 2000). More rigorous regularity conditions assure that the NLS estimator is also asymptotically normally distributed.

Since the NLS estimator for $STAR$ models has no closed-form solution, appropriate numerical techniques should be applied to obtain the estimates. The optimisation procedure may be greatly supported with the initial values. In particular, it is sensible to obtain them by searching over the grid for values of γ and $\boldsymbol{c}$ which minimise the sum of squared residuals in the conditionally linear model. Unfortunately, even feeding the optimisation procedure with very good starting values does not guarantee a successful estimation, especially in small samples. The problem arises because an adequate estimation of γ and $\boldsymbol{c}$ requires much information on the curvature of the transition function, i.e. a large number of observations located in the neighbourhood of $\boldsymbol{c}$, which is unlikely to happen in small samples.[63]

Despite the many attempts and experiments (including, e.g. a lower and upper bound, restrictions for the parameters and iterative parameter-by-parameter estimation with updating), we failed to find a procedure which would allow to successfully estimate all of the parameters for all of the models. Therefore, we calibrated the values of γ and $\boldsymbol{c}$ on the basis of the conditional sum of squared residuals, allowing:

- rescaled[64] parameter γ to take a value from 0.1 to 32 with an intercept 0.1
- parameter c to take a value from $p_5(s_t)$ to $p_{95}(s_t)$ (i.e. from the $5th$ to $95th$ percentile of the transition variable) with an intercept $\frac{p_{95}(s_t)-p_5(s_t)}{100}$ (for $LSTAR1$ and $ESTAR$)

[63] See van Dijk, Teräsvirta and Franses (2002) or Teräsvirta, Tjøstheim and Granger (2010 Ch. 16.3.3) for a short discussion and further references.

[64] To make the parameter γ scale-free, it should be divided by the sample standard deviation of the transition variable (for $LSTAR1$) or its square ($LSTAR2$ and $ESTAR$) (Teräsvirta, Tjøstheim and Granger 2010 Ch. 16.3.3).

- parameter c_1 to take a value from $p_5(s_t)$ to $p_{50}(s_t)$ with an intercept $\frac{p_{50}(s_t)-p_5(s_t)}{50}$ (for $LSTAR2$)
- parameter c_2 to take a value from $p_{50}(s_t)$ to $p_{95}(s_t)$ with an intercept $\frac{p_{50}(s_t)-p_5(s_t)}{50}$ (for $LSTAR2$)

It is worth noting that the adopted solution is much more flexible and less arbitrary than the ones chosen, e.g. by Weise (1999) or Huh and Lee (2002), who also found difficulties in 'pure estimation' of the $STAR$ models. Since the equations in our baseline linear model contain $AR(1)$ error terms, despite the aforementioned calibration the NLS estimation is employed anyway.

6.2.4 Model selection

The model selection stage aims to choose model(s) which will later serve as a basis for both econometric and economic inference. Therefore, at this stage not only should the final specification of the transition function be selected but also possible restrictions on the model parameters need to be taken into account. Teräsvirta, Tjøstheim and Granger (2010, Ch. 16.3.2) showed that there are many possible restrictions (and their combinations) which may be potentially considered. However, since the main aim of this thesis is to verify the assumption of linearity and state-independency of the monetary transmission mechanism, we find the restrictions $\psi_j = 0$ in (6.1) to be our major focus point. As in every equation in our baseline model, there are four parameters containing information on the structural parameters, so in every case we have $\binom{4}{1} + \binom{4}{2} + \binom{4}{3} = 14$ sets of restrictions between the baseline linear model and the model where no ψ_j is restricted to 0.

Bearing in mind that in some cases we want to select the final model among many $LSTAR1$, $LSTAR2$ and $ESTAR$ specifications which are not nested in one another, we cannot adopt a standard procedure of model selection based on the Wald or LR tests. Such a procedure is also infeasible due to the aforementioned fact that the nuisance parameters γ and $\boldsymbol{c}$ are not identified under the linear model against which we would like to compare the estimated $STAR$ models as well. Then the information criteria seem to be a natural choice. An additional advantage of using the information criteria is that the finally selected $STAR$ models are not only statistically significantly 'better' but also more parsimonious than the linear baseline. In other words the proposed approach verifies whether it econometrically pays off to make the effort of switching from the standard linear approach to the $STAR$ framework.

Econometricians usually point out that the Bayesian or Schwarz Information Criterion (BIC/SIC) has better properties than the Akaike Information Criterion (AIC) since the BIC/SIC is derived under Bayesian methods and it is a consistent model selector, while AIC lacks a Bayesian background and tends to select models which are overparameterised (see, e.g. Kennedy 2008 Ch. 6). Burnham and Anderson (2002) showed, however, that such statements should be treated as econometric 'half-truths' – both information criteria can be obtained via Bayesian methods but under different priors, and both information criteria are consistent but under different assumptions. More specifically, the AIC asymptotically chooses the best model if the true model is not among the available ones, while the BIC/SIC selects consistently if the true model is obtainable. Therefore, the choice should be based on whether the performed analysis aims to explore the available data with neither a strong prior nor null hypothesis or rather confronts a particular prior or hypothesis with the data.

Taking the above-mentioned characteristics of the information criteria into consideration, we propose to use the BIC/SIC to decide whether any $STAR$ model is better than the linear baseline and, if positive, to select the best $STAR$ model with the use of the AIC. As far as we know, this is the first time such a procedure has been proposed, nevertheless, we believe that it fits the research context better than choosing a single information criterion. Since the linear baseline is our prior and null hypothesis that we want to confront with the data, it is sensible to use the BIC/SIC as a consistent selector if the true model is among those being analysed. On the other hand, once we find that our prior and null hypothesis of linearity is rejected, we know that all of the $STAR$ models we are considering are just a (rough) approximation of the true model and we are not able to find the real data-generating process. Then it is desirable to choose an AIC which consistently selects the best model if the true model is out of reach.

6.2.5 Evaluation

The evaluation stage is important because it allows to verify whether the assumptions underlying the estimation process are satisfied from a statistical point of view. In particular, we focus our attention on testing the assumption of no autocorrelation which is crucial for the consistency of the NLS estimator. Moreover, we test whether the functional form is not misspecified. Although we already know that the estimated models are just rough approximations of the data-generating process, and in that sense their functional forms are not correct, we should know how reliable the employed functional form is and how cautiously we should interpret the estimation results.

We perform a test of no autocorrelation in the general form as was proposed by Teräsvirta, Tjøstheim and Granger (2010, Ch. 16.3.4) and van Dijk, Teräsvirta and Franses (2002):

1. Collect the residuals e_t and the number of estimated parameters p_0 and compute the residual sum of squares SSR_0 and gradients evaluated at the estimated parameters $\boldsymbol{g}_t$ from the estimated $STAR$ model.

2. Regress e_t on $\boldsymbol{g}_t$ and e_{t-1}, e_{t-2}, ..., e_{t-q} up to the selected lag order, collect the number of estimated parameters p_1 and compute the residual sum of squares SSR_1.

3. Compute the χ^2 or the F version of the LM-test statistic:

$$LM_{\chi^2} = T\frac{SSR_0 - SSR_1}{SSR_0} \qquad \xrightarrow{D} \chi^2(p_1 - p_0) \tag{6.5}$$

$$LM_F = \frac{(SSR_0 - SSR_1)/(p_1 - p_0)}{SSR_1/(T - p_1)} \qquad \overset{approx.}{\sim} F(p_1 - p_0, T - p_1) \tag{6.6}$$

We implement two amendments to the above procedure. The first amendment is suggested by van Dijk, Teräsvirta and Franses (2002), who recommended that e_t be substituted with its orthogonalised against $\boldsymbol{g}_t$ counterpart, since optimisation algorithms do not guarantee exact orthogonality of e_t and $\boldsymbol{g}_t$. The second modification, recommended by Teräsvirta, Tjøstheim and Granger (2010, Ch. 16.3.4) and also known from the Breusch-Godfrey test, aims to alleviate the size distortion problem by substituting missing lags of e_t with zeros. As in the case of the baseline linear model diagnostic, we set $q = 12$.

As far as testing for the correct functional form is concerned, due to a too small sample size and computational problems we are not able to neither test for parameter constancy nor perform some of the parameter-consuming tests of no additive nonlinearity as was suggested by Teräsvirta, Tjøstheim, and Granger (2010, Ch. 16.3.4).[65] In such a situation the authors recommended that the LM version of the Ramsey-RESET test be performed. The procedure is

[65] A test for the additive $STAR$ model would require that one estimate a fully specified $STAR$ model extended with polynomial components (in our case 12 or 16 additional parameters), while a test for more general additive nonlinearity would require, in our case, that we estimate at least 30 parameters in total (for the third-order polynomial).

analogous as in the test of no autocorrelation, but lags of e_t should be substituted with powers of fitted values from the $STAR$ model. As was the case before, we set the maximum power J to 3 or 4.

Moreover, we also report the results of the Jarque-Bera normality test that is applied to the residuals. The results tell whether the estimates may be perceived as obtained via the Maximum Likelihood or Quasi-Maximum Likelihood Estimation (MLE or QMLE). Additionally, non-normality of residuals may suggest that we treat the results of other diagnostic tests with greater cautiousness since the empirical distributions of test statistics may deviate from the theoretical distributions to a larger extent than otherwise. On the other hand, it is worth emphasising that any stochastic simulation of the generalised impulse response functions would be based on bootstrapped rather than on theoretical distributions of shocks, which immunise the impulse responses against non-normality of the model residuals.

The literature does not suggest any special need for ex-post-testing for heteroscedasticity. On the one hand, the homoscedasticity assumption was already verified before linearity testing (i.e. when it truly mattered), while, on the other hand, in the context of nonlinearity, heteroscedasticity tests should be regarded as tests for general misspecification rather than as tests for true heteroscedasticity, especially for quarterly macroeconomic data.[66] Finally, in this thesis we perform no statistical inference based on the coefficients' variance-covariance matrix from the estimated $STAR$ models.

At the end of this paragraph it is important to emphasise that the suggested tests are not specific about what should be done if the null hypothesis is rejected. Teräsvirta, Tjøstheim and Granger (2010, Ch. 16.3.4) claimed that the tests discussed here should be perceived as various tests for general misspecification without being precise about its nature. Then 'the idea of extending the model further has to be weighted against other considerations such as the risk of overfitting'. They also found it important to apply low significance levels as to 'obtain some protection against overfitting'. Therefore, even if the null hypothesis is rejected at a 1% significance level, we treat the negative result as information on the model's shortcomings rather than as an incentive to modify the model. Bearing in mind the large number of estimated equations, we want to stick to a unified framework of modelling without

[66] See, e.g. Teräsvirta, Tjøstheim and Granger (2010, Ch. 16.3.4) for a short discussion on the reasonableness of testing for heteroscedasticity in the context of the $STAR$ framework, or Kennedy (2008, Ch. 8) for more general considerations regarding relations between problems of heteroscedasticity and misspecification.

any discretionary departures for individual equations.[67] Then there might be two extreme approaches as to how to treat the (generalised) impulse response functions obtained from models whose certain equations were rejected by the diagnostic tests:

- treat the obtained results as non-existent since they are unreliable due to the inconsistency of the estimator
- treat the obtained results very cautiously as a rough approximation.

Whenever we analyse impulse response functions based on such models in section 7, we will very explicitly inform about the negative results of the diagnostic tests.

6.2.6 Methodological remarks

In our case the estimated $STAR$ equations take the following general forms:

$$\pi_t = \varphi_{11} + \varphi_{12}\pi_{t-1} + \varphi_{13}x_{t-1} + \varphi_{14}i_{t-1} + \\ + (\psi_{11} + \psi_{12}\pi_{t-1} + \psi_{13}x_{t-1} + \psi_{14}i_{t-1})G(s_t;\gamma,\boldsymbol{c}) + \varphi_{15}\epsilon_{\pi,t-1} + \nu_{\pi,t} \quad (6.7)$$

$$x_t = \varphi_{21} + \varphi_{22}\pi_{t-1} + \varphi_{23}x_{t-1} + \varphi_{24}i_{t-1} + \\ +(\psi_{21} + \psi_{22}\pi_{t-1} + \psi_{23}x_{t-1} + \psi_{24}i_{t-1})G(s_t;\gamma,\boldsymbol{c}) + \varphi_{25}\epsilon_{x,t-1} + \nu_{x,t} \quad (6.8)$$

$$i_t = \varphi_{31} + \varphi_{32}\pi_t + \varphi_{33}x_t + \varphi_{34}i_{t-1} + \\ +(\psi_{31} + \psi_{32}\pi_t + \psi_{33}x_t + \psi_{34}i_{t-1})G(s_t;\gamma,\boldsymbol{c}) + \varphi_{35}\epsilon_{i,t-1} + \nu_{i,t} \quad (6.9)$$

Since, analogously as in the case of the baseline model, the $STAR$ models are estimated in their reduced forms, the estimated parameters are not very informative themselves. Bearing in mind the scope of this thesis, however, we are particularly interested in the models' response to monetary policy shock – the only type of shock which is structurally identified in the model owing to one-to-one mapping between the structural and reduced form of the Taylor rule. Therefore, in the following subsections we present and discuss only the final model selections ($LSTAR1$, $LSTAR2$, $ESTAR$ or $LINEAR$) and the results of diagnostic tests as to provide information whether the estimated equations are correctly specified.

[67] Since the test equations in section 5 are based on the Taylor approximation, there might exist many locally equivalent alternatives to the $STAR$ specification, some of which could be potentially preferred over both the $STAR$ specification and the linear baseline.

Detailed estimates of the finally selected $STAR$ models are available in Tables A7.1 – A7.11 in Appendix A7.

6.3 Modelling nonlinearity

In this subsection we briefly describe the results of modelling the (explicit) nonlinearity of the monetary transmission mechanism.

As was shown in Table 5.2, the output gap equation is the only one which exhibits statistically significant (at a 5% significance level) nonlinearity (with respect to x_{t-1}, but only for $J = 4$). The performed procedure of specifying the preliminary functional form (see Table A6.1 in Appendix A.6) suggests the $LSTAR1$ specification as the only one which should be considered against the linear baseline. According to the information criteria, the finally estimated $LSTAR1$ model is better than the linear one, while the diagnostic tests reveal no problems with autocorrelation, the incorrect functional form or a lack of residual normality.

Table 6.1 Final model selection and p-values of diagnostic tests when modelling nonlinearity

Eq.	z_t	Functional form	H_0: no autocorrelation		H_0: correct functional form				H_0: normal distribution
					Maximum power $J = 3$		Maximum power $J = 4$		Jarque-Bera
			F	χ^2	F	χ^2	F	χ^2	
x_t	x_{t-1}	$LSTAR1$	0.733	0.597	0.214	0.173	0.222	0.173	0.913

In summary, we find that the estimated $STAR$ model appropriately incorporates the nonlinear nature of the output gap equation and that such a model may be exploited to calculate generalised impulse responses in section 7 without any additional reservations regarding diagnostic tests.

6.4 Modelling indirect forms of nonlinearity

Analogously as in the previous subsection, here we briefly describe the results of modelling indirect forms of nonlinearity of the monetary transmission mechanism.

The tests performed in paragraph 5.2.3 (Table 5.3) show that in 5 cases the assumption of state-independency is rejected. Nevertheless, only in 3 cases (once for each equation) are the estimated $STAR$ models (see Table A6.2 in Appendix A.6 for preliminary specifications) found to be more parsimonious than the linear baseline. Although, such results may suggest that either the 'degree of state-dependency' is somewhat overestimated by the tests being performed or the detected state-dependency should be modelled with the use of other models than $STAR$ models (e.g. due to the aforementioned local equivalency of the nonlinear specification which is an alternative to the $STAR$ specification), it is important to recall once again that criterions of statistical significance and parsimoniousness are not equivalent.

At the model selection stage, according to the employed procedure, 3 $STAR$ models (out of 5 cases) are selected. These are the:

- inflation equation, state-dependent with respect to the measure of central tendency of the interest rate
- output gap equation, state-dependent with respect to the measure of central tendency of the output gap
- interest rate equation, state-dependent with respect to the measure of variance of the output gap.

Table 6.2 Final model selection when modelling indirect forms of nonlinearity

s_t	inflation equation	output gap equation	interest rate equation
π_{t-1}^{SM}	$LINEAR$	$LINEAR$	$LINEAR$
x_{t-1}^{SM}	$LINEAR$	$LSTAR1$	$LINEAR$
i_{t-1}^{SM}	$LSTAR1$	$LINEAR$	$LINEAR$
π_{t-1}^{SV}	$LINEAR$	$LINEAR$	$LINEAR$
x_{t-1}^{SV}	$LINEAR$	$LINEAR$	$LSTAR1$
i_{t-1}^{SV}	$LINEAR$	$LINEAR$	$LINEAR$

The diagnostic tests performed here reveal that none of the estimated equations suffers from the problem of autocorrelation or incorrect functional form, although one equation (i_t with respect to x_{t-1}^{SV}) has a non-normal distribution at a 5% significance level (but normal at 1%). Bearing in mind the suggestion by Teräsvirta, Tjøstheim and Granger (2010, Ch. 16.3.4), i.e. to apply low significance levels when performing $STAR$ diagnostic tests, we find the obtained results satisfactory.

Table 6.3 P-values of diagnostic tests when modelling indirect forms of nonlinearity

Eq.	s_t	Functional form	H_0: no autocorrelation		H_0: correct functional form				H_0: normal distribution
					Maximum power $J = 3$		Maximum power $J = 4$		Jarque-Bera
			F	χ^2	F	χ^2	F	χ^2	
π_t	i_{t-1}^{SM}	$LSTAR1$	0.970	0.929	0.753	0.716	0.873	0.842	0.270
x_t	x_{t-1}^{SM}	$LSTAR1$	0.215	0.161	0.519	0.481	0.486	0.436	0.599
i_t	x_{t-1}^{SV}	$LSTAR1$	0.619	0.492	0.146	0.118	0.269	0.221	0.010

In summary, we find that indirect forms of nonlinearity play an important role in the monetary transmission mechanism. An analysis of asymmetry of monetary transmission is, to a great extent, based on the results obtained here. Thus, it is all the more important to recall once again that diagnostic tests show that all of the estimated equations are correctly specified at a 1% significance level.

6.5 Modelling state-dependency

In this subsection we test for state-dependency. Analogously as in the previous section, we divide the subsection into 10 paragraphs corresponding to the theoretical sources of state-dependency which were discussed in sections 2 and 3.

6.5.1 State-dependency with respect to measures of business cycle and climate

Despite a very rich theoretical background, according to the adopted selection procedure (see Table A6.3 in Appendix A.6 for preliminary specifications) the inflation equation reveals no state-dependency with respect to the selected measures of business cycle and climate. On the other hand, however, we find rich evidence of such state-dependency for the output gap and the interest rate equations. In the first case, $STAR$ models are selected for each variable, while in the latter case – for each variable except for the Consumer Sentiment Index.

The diagnostic tests show that only once (the test of a correct functional form for the output gap equation with respect to capacity utilisation) are the estimated p-values lower than a 1% significance level. It may be expected that the $STAR$ framework is not potent to account appropriately for state-dependency of the output gap equation with respect to capacity utilisation. Therefore, as was already mentioned, results based on such estimates should be treated with the utmost caution. In three cases the p-values are lower than 5% but higher than 1% – a result we find satisfactory in the research context.

Table 6.4 Final model selection when modelling state-dependency with respect to measures of business cycle and climate

s_{kt}^{j}	Short data description	inflation equation	output gap equation	interest rate equation
cu_t	Capacity utilization	$LINEAR$	$LSTAR1$	$LSTAR1$
ai_ma_t	Chicago Fed National Activity Index: three month moving average	$LINEAR$	$ESTAR$	$LSTAR1$
ai_di_t	Chicago Fed National Activity Index: diffusion index	$LINEAR$	$LSTAR1$	$LSTAR1$
cs_t	University of Michigan: Consumer Sentiment Index©	$LINEAR$	$LSTAR1$	$LINEAR$

Table 6.5 P-values of diagnostic tests when modelling state-dependency with respect to measures of business cycle and climate

Eq.	s_{kt}^{j}	Functional form	H_0: no autocorrelation		H_0: correct functional form				H_0: normal distribution
					Maximum power $J = 3$		Maximum power $J = 4$		Jarque-Bera
			F	χ^2	F	χ^2	F	χ^2	
x_t	cu_t	$LSTAR1$	0.994	0.986	0.000	0.000	0.000	0.000	0.756
	ai_ma_t	$ESTAR$	0.041	0.031	0.086	0.067	0.171	0.135	0.594
	ai_di_t	$LSTAR1$	0.716	0.608	0.142	0.118	0.228	0.190	0.422
	cs_t	$LSTAR1$	0.168	0.109	0.308	0.260	0.486	0.421	0.367
i_t	cu_t	$LSTAR1$	0.023	0.019	0.350	0.306	0.516	0.459	0.062
	ai_ma_t	$LSTAR1$	0.823	0.732	0.242	0.209	0.301	0.257	0.661
	ai_di_t	$LSTAR1$	0.976	0.953	0.499	0.460	0.710	0.670	0.321

6.5.2 State-dependency with respect to measures of labour market conditions

Similarly as in the previous paragraph, and despite sound theoretical premises, we find no $STAR$-type state-dependency of the inflation equation with respect to measures of labour market conditions, combined with evidence of such state-dependency for the output gap and interest rate equations (2 and 1 models, respectively, out of 4 chances). Such a pattern suggests that labour market climate does not substantially affect the price-setting mechanism (e.g. via downward wage rigidity) or the underlying impact cannot be successfully approximated with the use of the $STAR$ framework.[68] At the same time labour market condition seem to play an important role in shaping investment and consumption decision-making processes, while the monetary authorities seem to adjust their policy rule in line with the evolution of situation on the labour market.

[68] It is worth recalling that, since the model is estimated in its reduced form, the presented interpretation should be treated with caution.

Likewise, the diagnostic tests detect that in only one case is the output gap equation (with respect to the Labour Market Conditions Index) claimed to have an incorrect functional form at a 1% significance level, which should induce us to look at the obtained estimates carefully.

Table 6.6 Final model selection when modelling state-dependency with respect to measures of labour market conditions

s_{kt}^{j}	short data description	inflation equation	output gap equation	interest rate equation
ur_t	Civilian unemployment rate	$LINEAR$	$LINEAR$	$LINEAR$
$w\&s_t$	Compensation of employees: wages and salaries, annualised percent change from quarter ago	$LINEAR$	$LSTAR1$	$LINEAR$
$lfpr_t$	Civilian labour force participation rate	$LINEAR$	$LINEAR$	$LINEAR$
$lmci_t$	Labour Market Conditions Index	$LINEAR$	$LSTAR1$	$LSTAR1$

Table 6.7 P-values of diagnostic tests when modelling state-dependency with respect to measures of labour market conditions

Eq.	s_{kt}^{j}	Functional form	H_0: no autocorrelation		H_0: correct functional form				H_0: normal distribution
					Maximum power $J = 3$		Maximum power $J = 4$		Jarque-Bera
			F	χ^2	F	χ^2	F	χ^2	
x_t	$w\&s_t$	$LSTAR1$	0.026	0.024	0.294	0.258	0.413	0.364	0.753
	$lmci_t$	$LSTAR1$	0.497	0.391	0.000	0.000	0.000	0.000	0.738
i_t	$lmci_t$	$LSTAR1$	0.889	0.799	0.431	0.380	0.610	0.549	0.309

6.5.3 State-dependency with respect to measures of financial conditions

Since we have employed 18 measures of financial conditions, it comes as no surprise that the $STAR$ models are preferred over the linear baseline many times over. Specifically, we find 1, 9 and 4 such cases for the inflation, output gap and interest rate equations, respectively.

As far as the diagnostic tests are considered, the adopted functional form is discovered to be incorrect at a 1% level for the interest rate equation with respect to the CredAbility Consumer Distress Index.

Table 6.8 Final model selection when modelling state-dependency with respect to measures of financial conditions

s_{kt}^{j}	short data description	inflation equation	output gap equation	interest rate equation
	Indices of financial conditions			
$ccdi_t$	CredAbility Consumer Distress Index	$LINEAR$	$ESTAR$	$LSTAR1$
$fcnls_t$	Chicago Fed National Financial Conditions Nonfinancial Leveral Subindex	$LINEAR$	$LINEAR$	$LINEAR$
$fcls_t$	Chicago Fed National Financial Conditions Leverage Subindex	$LINEAR$	$LSTAR1$	$LINEAR$
$fccs_t$	Chicago Fed National Financial Conditions Credit Subindex	$LINEAR$	$LSTAR1$	$LINEAR$
$fcrs_t$	Chicago Fed National Financial Conditions Risk Subindex	$LSTAR2$	$LINEAR$	$LINEAR$
$afci_t$	Chicago Fed Adjusted National Financial Conditions Index	$LINEAR$	$LINEAR$	$LINEAR$
fci_t	Chicago Fed National Financial Conditions Index	$LINEAR$	$LINEAR$	$LINEAR$
	Monetary aggregates			
mb_t	Board of governors monetary base, annualised percent change from quarter ago	$LINEAR$	$LSTAR1$	$LINEAR$
mb_gdp_t	Board of governors monetary base to gross domestic product (nominal ratio)	$LINEAR$	$LINEAR$	$LINEAR$
mzm_t	MZM (money zero maturity) stock, annualised percent change from quarter ago	$LINEAR$	$LINEAR$	$LSTAR1$
$m2_t$	M2 money stock, annualised percent change from quarter ago	$LINEAR$	$LINEAR$	$LSTAR1$
	Interest rate quality spreads			
baa_i_t	Moody's seasoned Baa corporate bond minus federal funds rate	$LINEAR$	$LINEAR$	$LINEAR$
aaa_i_t	Moody's seasoned Aaa corporate bond minus federal funds rate	$LINEAR$	$LINEAR$	$LINEAR$
	Quality of credit portfolio			
llr_tl_t	Loan loss reserve to total loans for all U.S. banks	$LINEAR$	$LINEAR$	$LINEAR$
fat_t	Number of failures and assistance transactions of all institutions for the United States	$LINEAR$	$LINEAR$	$LINEAR$
nl_tl_t	Nonperforming loans to total loans for all U.S. banks	$LINEAR$	$LSTAR1$	$LINEAR$
dr_t	Delinquency rate on all loans	$LINEAR$	$LSTAR1$	$LINEAR$
cor_t	Charge-off rate on all loans	$LINEAR$	$LINEAR$	$LINEAR$

Table 6.9 P-values of diagnostic tests when modelling state-dependency with respect to measures of financial conditions

Eq.	s_{kt}^{j}	Functional form	H_0: no autocorrelation		H_0: correct functional form				H_0: normal distribution
					Maximum power $J = 3$		Maximum power $J = 4$		Jarque-Bera
			F	χ^2	F	χ^2	F	χ^2	
π_t	$fcrs_t$	$LSTAR2$	0.458	0.341	0.259	0.219	0.127	0.098	0.362
x_t	$ccdi_t$	$ESTAR$	0.402	0.309	0.013	0.011	0.029	0.023	0.950
	$fcls_t$	$LSTAR1$	0.791	0.667	0.525	0.475	0.351	0.290	0.492
	$fccs_t$	$LSTAR1$	0.463	0.346	0.082	0.063	0.113	0.087	0.832
	mb_t	$LSTAR1$	0.446	0.331	0.635	0.596	0.315	0.263	0.720
	nl_tl_t	$LSTAR1$	0.759	0.642	0.086	0.066	0.179	0.142	0.983
	dr_t	$LSTAR1$	0.785	0.674	0.383	0.338	0.041	0.030	0.517
i_t	$ccdi_t$	$LSTAR1$	0.041	0.035	0.002	0.002	0.003	0.003	0.084
	mzm_t	$LSTAR1$	0.814	0.708	0.699	0.665	0.215	0.173	0.833
	$m2_t$	$LSTAR1$	0.771	0.671	0.224	0.192	0.229	0.191	0.062

6.5.4 State-dependency with respect to measures of uncertainty

The adopted selection procedure detects no role for the selected measures of uncertainty as sources of state-dependency of the $STAR$-type for the inflation or interest rate equation, while such a role is found for the output gap (2 times out of 2 chances).

The diagnostic tests reveal no problems at a 1% significance level.

Table 6.10 Final model selection when modelling state-dependency with respect to measures of uncertainty

s_{kt}^{j}	short data description	inflation equation	output gap equation	interest rate equation
$epui_t$	Economic Policy Uncertainty Index for United States by Baker, Bloom and Davis (2013)	$LINEAR$	$LSTAR1$	$LINEAR$
$emeui_t$	Equity Market-related Economic Uncertainty Index by Baker, Bloom and Davis (2013)	$LINEAR$	$LSTAR1$	$LINEAR$

Table 6.11 P-values of diagnostic tests when modelling state-dependency with respect to measures of uncertainty

Eq.	s_{kt}^{j}	Functional form	H_0: no autocorrelation		H_0: correct functional form				H_0: normal distribution
					Maximum power $J=3$		Maximum power $J=4$		Jarque-Bera
			F	χ^2	F	χ^2	F	χ^2	
x_t	$epui_t$	$LSTAR1$	0.750	0.646	0.053	0.043	0.097	0.078	0.796
	$emeui_t$	$LSTAR1$	0.310	0.233	0.361	0.322	0.266	0.225	0.540

6.5.5 State-dependency with respect to measures of globalisation

The pattern from paragraphs 6.5.1, 6.5.2 and 6.5.4 repeats when modelling state-dependency with respect to measures of globalisation. According to the adopted procedure of model selection, the linear inflation equation is found to be more parsimonious than the proposed $STAR$ alternatives, which is at odds with the suggestions in the literature. On the other hand, a $STAR$-type state-dependency is detected for the output gap (2 times out of 10 chances) and the interest rate equations (3 times out of 20 chances), although in these cases theoretical support for such a result is much weaker than for the inflation equation.

The diagnostic tests detect a lack of normal distribution of residuals for one interest rate equation at a 1% significance level. Therefore, the results of the two other diagnostic tests should be treated with greater caution since the small-sample properties of the test statistics may significantly deviate from the nominal ones.

Table 6.12 Final model selection when modelling state-dependency with respect to measures of globalisation

s_{kt}^{j}	short data description	inflation equation	output gap equation	interest rate equation
	World data			
$wgdp_t$	World gross domestic product, constant 2005 dollar, annualised percent change from quarter ago	$LINEAR$	$LINEAR$	$LSTAR1$
ws_gdp_t	World gross savings, percent of world gross domestic product (nominal ratio)	$LINEAR$	$LSTAR1$	$LINEAR$
wds_gdp_t	World gross domestic savings, percent of world gross domestic product (nominal ratio)	$LINEAR$	$LINEAR$	$LINEAR$
we_gdp_t	World exports of goods and services, percent of world gross domestic product, (nominal ratio)	$LINEAR$	$LINEAR$	$LSTAR1$
	U.S. data			
e_gdp_t	Real exports of goods and services, percent of real gross domestic product (real ratio)	$LINEAR$	$LINEAR$	$LSTAR2$
i_gdp_t	Real imports exports of goods and services, percent of real gross domestic product (real ratio)	$LINEAR$	$LINEAR$	$LINEAR$
ca_gdp_t	Balance on current account, percent of gross domestic product (nominal ratio)	$LINEAR$	$ESTAR$	$LINEAR$
aa_gdp_t	U.S. assets abroad, percent of gross domestic product (nominal ratio)	$LINEAR$	$LINEAR$	$LINEAR$
fa_gdp_t	Foreign assets in the U.S., percent of gross domestic product (nominal ratio)	$LINEAR$	$LINEAR$	$LINEAR$
usd_t	Trade weighted U.S. dollar index, annualised percent change from quarter ago	$LINEAR$	$LINEAR$	$LINEAR$

Table 6.13 P-values of diagnostic tests when modelling state-dependency with respect to measures of globalisation

Eq.	s_{kt}^{j}	Functional form	H_0: no autocorrelation		H_0: correct functional form				H_0: normal distribution
					Maximum power $J = 3$		Maximum power $J = 4$		Jarque-Bera
			F	χ^2	F	χ^2	F	χ^2	
x_t	ws_gdp_t	$LSTAR1$	0.806	0.698	0.834	0.812	0.876	0.851	0.710
	ca_gdp_t	$ESTAR$	0.393	0.287	0.206	0.171	0.308	0.256	0.770
i_t	$wgdp_t$	$LSTAR1$	0.494	0.342	0.858	0.834	0.768	0.718	0.197
	we_gdp_t	$LSTAR1$	0.695	0.555	0.024	0.017	0.025	0.017	0.000
	e_gdp_t	$LSTAR2$	0.197	0.147	0.261	0.227	0.440	0.391	0.351

6.5.6 State-dependency with respect to measures of composition of the economy

As in the case of state-dependency with respect to measures of uncertainty, according to the adopted procedure of model selection, the linear inflation and interest rate equations are found to be more parsimonious than concurrent $STAR$ models in which the selected measures of composition of the economy are transition variables. At the same time, state-dependency of the $STAR$-type is identified for the output gap equation for both variables.

The diagnostic tests reveal no problems at a 1% significance level.

Table 6.14 Final model selection when modelling state-dependency with respect to measures of composition of the economy

s_{kt}^{j}	short data description	inflation equation	output gap equation	interest rate equation
$lshare_t$	Labour share in nonfarm business sector	$LINEAR$	$LSTAR1$	$LINEAR$
sva_gdp_t	Services: value added: percent of gross domestic product (nominal ratio)	$LINEAR$	$LSTAR1$	$LINEAR$

Table 6.15 P-values of diagnostic tests when modelling state-dependency with respect to measures of composition of the economy

Eq.	s_{kt}^{j}	Functional form	H_0: no autocorrelation		H_0: correct functional form				H_0: normal distribution
					Maximum power $J = 3$		Maximum power $J = 4$		Jarque-Bera
			F	χ^2	F	χ^2	F	χ^2	
x_t	$lshare_t$	$LSTAR1$	0.840	0.743	0.446	0.401	0.588	0.533	0.707
	sva_gdp_t	$LSTAR1$	0.921	0.863	0.434	0.394	0.122	0.098	0.684

6.5.7 State-dependency with respect to measures of potential growth and development

The algorithm of model selection employed here finds 2, 1 and 2 $STAR$ models (out of 6 chances) to be more parsimonious than the linear baselines of the inflation, output gap and interest rate equations, respectively. Interestingly, in all three cases the potential GDP is found to be a relevant transition variable – a result which is unique for all of the investigated transition variables. Such an outcome may question whether the standard approach of separate modelling of the business cycle and long-term growth is not an excessive simplification. After all, the long-run neutrality of monetary policy, which usually serves as a main justification for such a paradigm, does not imply that potential growth exerts no impact on e.g. price-setting and investment decisions of the firms or central bankers' decision making-process.

As far as the diagnostic tests are concerned, the only problem detected at a 1% significance level is the lack of normal distribution of residuals in one inflation equation (with respect to research and development to the GDP real ratio). As was already mentioned before, in such a case the results of the other diagnostic test for that equation should be treated with caution.

Table 6.16 Final model selection when modelling state-dependency with respect to measures of potential growth and development

s_{kt}^{j}	Short data description	inflation equation	output gap equation	interest rate equation
gdp_pot_t	Real potential gross domestic product, annualised percent change from quarter ago	$LSTAR1$	$LSTAR1$	$LSTAR1$
rd_gdp_t	Real gross domestic product: research and development, percent of real gross domestic product, (real ratio)	$LSTAR1$	$LINEAR$	$LINEAR$
rd_t	Real gross domestic product: research and development, annualised percent change from quarter ago	$LINEAR$	$LINEAR$	$LINEAR$
pa_r_t	Patent applications, residents, annualised percent change from quarter ago	$LINEAR$	$LINEAR$	$LINEAR$
pa_rn_t	Patent applications, residents + nonresidents, annualised percent change from quarter ago	$LINEAR$	$LINEAR$	$LINEAR$

Table 6.17 P-values of diagnostic tests when modelling state-dependency with respect to measures of potential growth and development

Eq.	s_{kt}^{j}	Functional form	H_0: no autocorrelation		H_0: correct functional form				H_0: normal distribution
					Maximum power $J = 3$		Maximum power $J = 4$		Jarque-Bera
			F	χ^2	F	χ^2	F	χ^2	
π_t	gdp_pot_t	$LSTAR1$	0.052	0.032	0.142	0.107	0.224	0.169	0.290
	rd_gdp_t	$LSTAR1$	0.488	0.383	0.429	0.389	0.442	0.392	0.001
x_t	gdp_pot_t	$LSTAR1$	0.381	0.291	0.855	0.838	0.957	0.949	0.774
i_t	gdp_pot_t	$LSTAR1$	0.666	0.524	0.490	0.440	0.647	0.590	0.186

6.5.8 State-dependency with respect to measures of financial development

In line with the model selection procedure, the inflation equation is found to reveal no state-dependency of the $STAR$-type with respect to the proposed transition variables, while assets held by money market mutual funds to GDP are detected to yield more parsimonious $STAR$ models for the output gap and the interest rate equations than the linear baselines.

No problems are detected at either a 1% or 5% significance level.

Table 6.18 Final model selection when modelling state-dependency with respect to measures of financial development of the economy

s_{kt}^{j}	Short data description	inflation equation	output gap equation	interest rate equation
	Money supply to GDP ratios			
mzm_gdp_t	MZM (money zero maturity) stock to gross domestic product (nominal ratio)	$LINEAR$	$ESTAR$	$LINEAR$
$m2\_gdp_t$	M2 money stock to gross domestic product (nominal ratio)	$LINEAR$	$LINEAR$	$LINEAR$

	Bank assets ratios			
ta_gdp_t	Total assets at all commercial banks, percent of gross domestic product (nominal ratio)	$LINEAR$	$LINEAR$	$LINEAR$
bc_gdp_t	Bank credit at all commercial banks, percent of gross domestic product (nominal ratio)	$LINEAR$	$LINEAR$	$LINEAR$
bc_d_t	Bank credit at all commercial banks, percent of deposits of all commercial banks	$LINEAR$	$LINEAR$	$LINEAR$
cl_gdp_t	Consumer loans at all commercial banks, percent of gross domestic product (nominal ratio)	$LINEAR$	$LINEAR$	$LINEAR$
rel_gdp_t	Real estate loans at all commercial banks, percent of gross domestic product (nominal ratio)	$LINEAR$	$LINEAR$	$LINEAR$
tas_ta_t	Treasury and agency securities at all commercial banks, percent of total assets of all commercial banks	$LINEAR$	$LINEAR$	$LINEAR$
ltd_d_t	Large time deposits at all commercial banks, percent of deposits of all commercial banks	$LINEAR$	$LINEAR$	$LINEAR$
nfb_cb_t	Total assets of nonfinancial corporate business, percent of total assets of all commercial banks	$LINEAR$	$LINEAR$	$LINEAR$
	Other measures			
mf_gdp_t	Money market mutual funds: total financial assets, percent of gross domestic product (nominal ratio)	$LINEAR$	$LSTAR1$	$LSTAR1$
nim_t	Net interest margin for all U.S. banks	$LINEAR$	$LINEAR$	$LINEAR$
roa_t	Return on average assets for all U.S. banks	$LINEAR$	$LINEAR$	$LINEAR$
$stck\_gdp_t$	Wilshire 5000 Full Cap Price Index©, percent of gross domestic product (nominal ratio)	$LINEAR$	$LINEAR$	$LINEAR$

Table 6.19 P-values of diagnostic tests when modelling state-dependency with respect to measures of financial development of the economy

Eq.	s_{kt}^{j}	Functional form	H_0: no autocorrelation		H_0: correct functional form				H_0: normal distribution
					Maximum power $J=3$		Maximum power $J=4$		Jarque-Bera
			F	χ^2	F	χ^2	F	χ^2	
x_t	mzm_gdp_t	$ESTAR$	0.220	0.144	0.018	0.012	0.021	0.014	0.947
	mf_gdp_t	$LSTAR1$	0.845	0.748	0.087	0.067	0.140	0.108	0.398
i_t	mf_gdp_t	$LSTAR1$	0.065	0.052	0.995	0.995	0.766	0.731	0.176

6.5.9 State-dependency with respect to variables related to the 'Greenspan conundrum'

According to the adopted model selection procedure and the hypothesis of the 'Greenspan conundrum', none of the $STAR$ models is preferred over the linear baseline for neither of the equations nor the two proposed transition variables. Therefore we claim that, even if the Federal Reserve truly lost its leverage over long-term rates in the Greenspan era, there is little evidence that such a situation substantially affected the monetary transmission mechanism. Alternatively, the *STAR* framework is not potent to depict the analysed relation properly.

Table 6.20 Final model selection when modelling state-dependency with respect to variables related to 'Greenspan conundrum'

s_{kt}^{j}	short data description	inflation equation	output gap equation	interest rate equation
$t10y\_3m_t$	10-year treasury constant maturity rate minus 3-month treasury constant maturity rate	$LINEAR$	$LINEAR$	$LINEAR$
$t10y\_ffr_t$	10-year treasury constant maturity rate minus federal funds rate	$LINEAR$	$LINEAR$	$LINEAR$

6.5.10 State-dependency with respect to variables related to some aspects of the Greenspan standard

The algorithm of model selection employed here finds none of the $STAR$ models to be preferred over the linear inflation equation. On the other hand, we detect 3 and 2 $STAR$ models to be more parsimonious than the linear output gap and interest rate equations, respectively. Interestingly, although we have selected 6 variables related to the dynamics of the stock market (i.e. from the economic perspective this is the same fundamental variable), the results are far from being robust.

Table 6.21 Final model selection when modelling state-dependency with respect to variables related to some aspects of Greenspan standard

s_{kt}^{j}	Short data description	inflation equation	output gap equation	interest rate equation
	Stock prices			
$sp500_t$	S&P 500©, annualised percent change from quarter ago	$LINEAR$	$ESTAR$	$LINEAR$
$nasd_t$	NASDAQ Composite Index©, annualised percent change from quarter ago	$LINEAR$	$LINEAR$	$LINEAR$
$wilsh_t$	Wilshire 5000 Full Cap Price Index©, annualised percent change from quarter ago	$LINEAR$	$LSTAR2$	$LINEAR$
djc_t	Dow Jones Composite©, annualised percent change from quarter ago	$LINEAR$	$LINEAR$	$LINEAR$
$djia_t$	Dow Jones Industrial Average©, annualised percent change from quarter ago	$LINEAR$	$LSTAR2$	$LINEAR$
$nasd100_t$	NASDAQ 100©, index, annualised percent change from quarter ago	$LINEAR$	$LINEAR$	$LINEAR$
	Real estate prices			
$spcs_t$	S&P/Case-Shiller U.S. National Home Price Index©, annualised percent change from quarter ago	$LINEAR$	$LINEAR$	$LSTAR1$
hpi_t	All-transactions house price index by US FHFA, annualised percent change from quarter ago	$LINEAR$	$LINEAR$	$LINEAR$
	Commodity prices			
wti_t	Spot oil price: West Texas Intermediate©, dollars per barrel, annualised percent change from quarter ago	$LINEAR$	$LINEAR$	$LSTAR1$
cpe_t	World Bank commodity price data: energy, annualised percent change from quarter ago	$LINEAR$	$LINEAR$	$LINEAR$
$cpne_t$	World Bank commodity price data: nonenergy, annualised percent change from quarter ago	$LINEAR$	$LINEAR$	$LINEAR$

Table 6.22 P-values of diagnostic tests when modelling when modelling state-dependency with respect to variables related to some aspects of Greenspan standard

Eq.	s_{kt}^{j}	Functional form	H_0: no autocorrelation		H_0: correct functional form				H_0: normal distribution
					Maximum power $J = 3$		Maximum power $J = 4$		Jarque-Bera
			F	χ^2	F	χ^2	F	χ^2	
x_t	$sp500_t$	$ESTAR$	0.207	0.135	0.081	0.060	0.171	0.130	0.508
	$wilsh_t$	$LSTAR2$	0.621	0.477	0.113	0.086	0.013	0.009	0.893
	$djia_t$	$LSTAR2$	0.612	0.484	0.823	0.800	0.031	0.023	0.870
i_t	$spcs_t$	$LSTAR1$	0.467	0.364	0.138	0.114	0.158	0.129	0.200
	wti_t	$LSTAR1$	0.333	0.213	0.558	0.503	0.440	0.367	0.124

The diagnostic tests show that at a 1% significance level one output gap equation (with respect to the Wilshire 5000 Full Cap Price Index©) may suffer from an incorrect functional form. Such a result suggests that state-dependency in the analysed relationship may deviate from the estimated state-dependency of the $STAR$-type.

6.6 Summary

In this subsection we specified, estimated and evaluated $STAR$ models which take into account explicit and implicit nonlinearity, and the state-dependency of the monetary transmission mechanism. The adopted procedure of model selection picked out a smaller number of $STAR$ models than was suggested by the linearity and state-independency tests performed in section 5, which means that in some cases the $STAR$ framework was incapable of delivering a more parsimonious nonlinear or state-dependent model than the linear baseline (despite the existence of nonlinearity and state-dependency at a 5% significance level). We argue that such results should not be interpreted as a weakness of the $STAR$ framework since criterions of statistical significance and parsimoniousness are not equivalent. As we argued in paragraph 6.2.4, the adopted approach ensures that the finally $STAR$ selected models are ‘better’ that the linear baseline not only from a statistical perspective but also a practice of econometric modelling.

Similarly as in section 5 we found (see Table 6.23) that the departure from the linear baseline was particularly strong for the output gap equation (especially in the case of state-dependency with respect to measures of business cycle and climate, uncertainty, and composition of the economy). On the other hand the results were very weak in the case of the inflation equation which suggests that time-dependent mechanisms of setting prices (e.g. Calvo 1983) provide a good enough modelling approximation of the real price-setting mechanisms. It also seems that the catalogue of relevant sources of state-dependency of the Taylor rule is relatively short and concentrates mainly on measures of business cycle and climate, monetary aggregates, some international aspects of globalisation, and real estate prices. Again it is worth recalling that our results contrast with the distribution of attention paid in the literature to the problem of nonlinearity and state-dependency of the Phillips curve, the IS curve, and the Taylor rule.

Table 6.23 Percentage of cases in which a $STAR$ model was found more parsimonious than the linear baseline

	inflation equation	output gap equation	interest rate equation	overall
nonlinearity*	11%	22%	9%	14%
state dependency	4%	33%	19%	19%
business cycle and climate	0%	100%	75%	58%
labour market conditions	0%	50%	25%	25%
financial conditions	6%	33%	17%	19%
- indices of financial conditions	14%	43%	14%	24%
- monetary aggregates	0%	25%	50%	25%
- interest rate quality spreads	0%	0%	0%	0%
- quality of credit portfolio	0%	40%	0%	13%
uncertainty	0%	100%	0%	33%
globalisation	0%	20%	30%	17%
- world data	0%	25%	50%	25%
- U.S. data	0%	17%	17%	11%
composition of the economy	0%	100%	0%	33%
potential growth and development	40%	20%	20%	27%
financial development	0%	14%	7%	7%
- money supply to GDP ratios	0%	50%	0%	17%
- bank assets ratios	0%	0%	0%	0%
- other measures	0%	25%	25%	17%
Greenspan conundrum	0%	0%	0%	0%
Greenspan standard	0%	27%	18%	15%
- stock prices	0%	50%	0%	17%
- real estate prices	0%	0%	50%	17%
- commodity prices	0%	0%	33%	11%

[*] including indirect nonlinearity

linear baseline	0%	(0%, 20%]	(20%, 40%]	(40%, 60%]	(60%, 80%]	(80%, 100%]	$STAR$ model

As far as diagnostic tests are concerned, in the case of some of the estimated models, problems with an incorrect functional form were detected at a 1% significance level. Then, although the estimated $STAR$ models are more parsimonious than the linear baseline, the adopted functional form should be treated as the second-best choice, which does not approximate nonlinearity or state-dependency with enough detail. On the other hand, it is worth emphasising that the diagnostic tests do not reveal problems with autocorrelation in any of the estimated $STAR$ models (at a 1% significance level). Such a result serves as evidence of properly specified system dynamics and is crucial from the perspective of the following section, in which an analysis of generalised impulse response functions is performed.

7. Asymmetry of monetary transmission

7.1 Introduction

In this section we analyse generalised impulse response functions in the context of asymmetry of monetary transmission. Bearing in mind the scope of the thesis, we are interested in the responses of model variables to interest rate shocks. As was defined in subsection 1.6, we distinguish three types of asymmetry: sign, size and state asymmetries. The sign and size asymmetries are discussed in subsection 7.2, while state asymmetry is discussed in subsection 7.3. In each case, before proceeding to a discussion of the results, we shortly present the applied method of deriving generalised impulse response functions.

7.2 Sign and size asymmetry

7.2.1 The method

The analysis of sign and size asymmetries of monetary transmission is based on the generalised impulse response functions derived from the $STAR$ model as was presented in subsections 6.3 (modelling nonlinearity) and the 3 $STAR$ models as were presented in subsection 6.4 (modelling indirect forms of nonlinearity).[69] For each transition variable which is mathematically potent to deliver sign and size asymmetries and was found to be an important source of explicit or implicit nonlinearity in subsections 6.3 and 6.4 (i.e. via the presented model selection procedure), we construct a system of three equations constituting a small model of the monetary transmission mechanism. As a result, we obtain a set of monetary transmission models in which at least one of the three equations is $STAR$. There are 4 such models, the list of which is presented in Table 7.1.

Table 7.1 Models of the monetary transmission mechanism employed for analysis of sign a size asymmetry

No.	z_t / s_t	inflation equation	output gap equation	interest rate equation
1	x_{t-1}	$LINEAR$	$LSTAR1$	$LINEAR$
2	x_{t-1}^{SM}	$LINEAR$	$LSTAR1$	$LINEAR$
3	i_{t-1}^{SM}	$LSTAR1$	$LINEAR$	$LINEAR$
4	x_{t-1}^{SV}	$LINEAR$	$LINEAR$	$LSTAR1$

[69] We choose only models which are mathematically potent to deliver sign and size asymmetries, i.e. for which there is a link between the value of the switching variable and the interest rate shock. In the case of all models from subsection 6.5, the values of the switching variables are unaffected by the values of endogenous variables and, in consequence, those models are not useful in the context of an analysis of sign and size asymmetries.

The rationale for using 4 models of monetary transmission is to check whether eventual sign and size asymmetries are prevalent features of the estimated (explicitly or implicitly) nonlinear models of monetary transmission or, perhaps, such a feature crucially depends on the choice of transition variable. Such a robustness check is important because the reviewed studies on asymmetries in monetary transmission for the U.S. economy (see Table A1.5 in Appendix A.1) show that empirical evidence regarding sign and size asymmetries is mixed. Conceivably, different results may come from different frameworks and different choices of threshold or transition variables. This problem is all the more important because the sign and size asymmetries are the by-products (mathematical consequences) of the adopted model functional forms rather than the intrinsic features of the impulse response functions. Since the impulse response functions are directly unobservable and must be derived conditionally on the estimated model, the adopted functional form of the model necessarily imposes strong restrictions on the functional form of the impulse responses. Therefore the properties of the impulse response functions cannot be precisely separated from the properties of the functional form of the model. Robustness checks help to alleviate this problem.

Bearing in mind that we are dealing with a nonlinear dynamic system and under such a setting a deterministic solution yields biased results, the generalised impulse response functions are calculated with the use of stochastic simulations with 10000 repetitions and bootstrap techniques. More precisely, innovations are drawn (in triplets) randomly with replacement from the model residuals assuming an empirical covariance matrix.

For each observation in a sample, we define 101 monetary shocks, which corresponds to percentiles (from $p_0 = min$ to $p_{100} = max$) of the empirical distribution of residuals from the relevant interest rate equation, while the actual values of the models' variables serve as a data environment for impulse propagation. In other words, the method of deriving generalised impulse response functions is designed to employ only the estimation sample and data which could have been 'seen' by the model – the aim of such a procedure is to avoid problems that were raised by the Lucas critique (1976).

As a result of the exercises which were described above, for each model, model variable, percentile of empirical distribution of interest shocks and point in time when the shock is initialised, we obtain a density of 10000 generalised impulse response functions:

$$\boldsymbol{GIRF}_{t+h,p}\left(y, \hat{v}_{i,t,p}, \Omega_t\right) = E\left\{y_{t+h} \middle| \hat{v}_{i,t,p}, \Omega_t\right\} - E\{y_{t+h}|\Omega_t\}, \qquad p = 0, \dots, 100,\ h \in \mathbb{N}^+$$

In such a notation, $y \in \{\pi, x, i\}$ designates a variable whose impulse response we are interested in; $\Omega_t = \{\pi_t, x_t, i_t\}$ represents the data environment in which impulse propagation takes place, while $\hat{v}_{i,t,p}$ is an interest rate shock defined on the basis of residuals from the relevant interest rate equation.

It is convenient to divide the obtained generalised impulse response functions by the initial shock so as to standardise the measure:

$$\boldsymbol{SGIRF}_{t+h,p}\left(y, \hat{v}_{i,t,p}, \Omega_t\right) = \frac{\boldsymbol{GIRF}_{t+h,p}(y, \hat{v}_{i,t,p}, \Omega_t)}{\hat{v}_{i,t,p}}, \qquad p = 0, \ldots, 100,\ h \in \mathbb{N}^+$$

In order to reduce the dimension of the analysed problem, we sum the values of each of the generalised impulse response functions over 16 periods after the shock is initialised and we receive distributions of 10000 scalars which stand for cumulative standardised responses of the chosen model variable to a particular percentile of the interest rate shock in a particular point in time:

$$\boldsymbol{CSGIRF}_{t,p}\left(y, \hat{v}_{i,t,p}, \Omega_t\right) = \sum_{h=0}^{16} \boldsymbol{SGIRF}_{t+h,p}\left(y, \hat{v}_{i,t,p}, \Omega_t\right) \qquad p = 0, \ldots, 100$$

Instead of mapping every single value out of 10000 repetitions, for each percentile of interest rate shock we track three measures which characterise the obtained distributions, i.e. the median, 5^{th} and 95^{th} percentiles:

$$CSGIRF_{t,p}^{M}(y, \Omega_t) = Median\left(\boldsymbol{CSGIRF}_{t,p}\left(y, \hat{v}_{i,t,p}, \Omega_t\right)\right) \qquad p = 0, \ldots, 100$$

$$CSGIRF_{t,p}^{P5}(y, \Omega_t) = Percentile_{5}\left(\boldsymbol{CSGIRF}_{t}\left(y, \hat{v}_{i,t,p}, \Omega_t\right)\right) \qquad p = 0, \ldots, 100$$

$$CSGIRF_{t,p}^{P95}(y, \Omega_t) = Percentile_{95}\left(\boldsymbol{CSGIRF}_{t}\left(y, \hat{v}_{i,t,p}, \Omega_t\right)\right) \qquad p = 0, \ldots, 100$$

Since the proposed measures are calculated for each point in time, we keep the sample average of the proposed measures and eliminate the influence of a particular data environment in which impulse propagation takes place[70]:

[70] In other words, for now we focus our attention on sign and size asymmetry and put aside state asymmetry for later analysis in subsection 7.3.

$$CSGIRF_p^M(y) = \frac{\sum_{t=1}^{T} CSGIRF_{t,p}^M(y,\Omega_t)}{T},$$

$$CSGIRF_p^{P5}(y) = \frac{\sum_{t=1}^{T} CSGIRF_{t,p}^{P5}(y,\Omega_t)}{T},$$

$$CSGIRF_p^{P95}(y) = \frac{\sum_{t=1}^{T} CSGIRF_{t,p}^{P95}(y,\Omega_t)}{T}, \qquad T = 71 \text{ (from 1988Q2 to 2005Q4)}$$

In the end, for each model and each model variable we have 101 observations of four variables: percentiles of empirical distribution of interest rate shock and corresponding measures of the median, 5^{th} and 95^{th} percentiles of the empirical distribution of a (cumulative standardised) generalised impulse response.

The idea behind the analysis which will be performed in the subsequent paragraphs is to check whether relations between the percentiles of the empirical distribution of interest rate shock and the proposed measures (or the ratios defined on their basis) are existent. In particular, we are interested what the roles of sign and size of the interest rate shock are. It is worth noting that the proposed measures should be constant for any linear model, while the model's nonlinearity implies their nonzero variance but not necessarily sign or size asymmetry.

In the following paragraphs we analyse and discuss three aspects of potential sign and size asymmetries of monetary transmission. In paragraph 7.2.2, where we look at $CSGIRF_p^M(y)$, we are dealing with the asymmetric effects of monetary policy shocks on model variables. In paragraph 7.2.3, on the basis of $CSGIRF_p^M(y)$, we define additional measures of effectiveness and efficiency of monetary policy shocks and we investigate the asymmetric behaviour of the proposed ratios. Paragraph 7.2.4, where we analyse the skew of the distribution, discusses asymmetric risk and structural uncertainty of monetary transmission. At the end of this subsection we present general conclusions from the performed analysis of sign and size asymmetries.

7.2.2 Asymmetric effects of monetary policy shocks on model variables

Being aware of the sign and size asymmetries of the effects of interest rate shocks lies at the heart of conducting a successful monetary policy. If restrictive actions are more powerful at influencing inflation or economic activity than positive actions, the monetary authorities have strong incentives to avoid continuous fine-tuning of the economy. Similarly, if large shocks have different unitary effects than small shocks, central bankers would probably not be indifferent to ‘serving a cold turkey’ and moving gradually when conducting the disinflation policy. In other words, sign and size asymmetries are closely related to fundamental dilemmas of the monetary policy strategy.

Taking into account the presented considerations, we estimate simple regressions:

$$CSGIRF_p^M(y) = \alpha^- \mathbb{1}_p^- + \alpha^+ \mathbb{1}_p^+ + \beta^- \hat{v}_{i,p}^- + \beta^+ \hat{v}_{i,p}^+ + \varepsilon_p \qquad p = 0, \dots, 100 \qquad (7.1)$$

where:

$$\mathbb{1}_p^- = \begin{cases} 1 & if \quad \hat{v}_{i,p} < 0 \\ 0 & if \quad \hat{v}_{i,p} \geq 0 \end{cases} \qquad \hat{v}_{i,p}^- = \begin{cases} \hat{v}_{i,p} & if \quad \hat{v}_{i,p} < 0 \\ 0 & if \quad \hat{v}_{i,p} \geq 0 \end{cases}$$

$$\mathbb{1}_p^+ = \begin{cases} 1 & if \quad \hat{v}_{i,p} \geq 0 \\ 0 & if \quad \hat{v}_{i,p} < 0 \end{cases} \qquad \hat{v}_{i,p}^+ = \begin{cases} \hat{v}_{i,p} & if \quad \hat{v}_{i,p} \geq 0 \\ 0 & if \quad \hat{v}_{i,p} < 0 \end{cases}$$

Using the Wald test, we test two main and two auxiliary null hypotheses:

1. $H_0^1: \alpha^- = \alpha^+ \; and \; \beta^- = \beta^+$
   a. $H_0^{1a}: \alpha^- = \alpha^+$
   b. $H_0^{1b}: \beta^- = \beta^+$
2. $H_0^2: \; \beta^- = \beta^+ = 0$

Under H_0^1 there is no sign asymmetry – $H_0^{1^a}$ assumes there is no difference in average effects of negative and positive interest rate shocks, while $H_0^{1^b}$ is specific that size asymmetry, if it exists, works in a similar manner for both negative and positive shocks. Similarly, H_0^2 assumes that there is no size asymmetry (expressed as a piecewise linear function between the size of a shock and the impulse response).

Table 7.2 presents the summary findings based on regressions (7.1) for $y \in \{\pi, x, i\}$. The subsequent columns contain information on the detected relations between α^- and α^+, β^- and β^+, and $\beta^{\mp}$ and 0 for $CSGIRF_p^M(\pi)$, $CSGIRF_p^M(x)$ and $CSGIRF_p^M(i)$ at a 5% significance level. More detailed regression outputs are available in Appendix A.8 in Tables A8.1 – A8.3.

Table 7.2 Summary results of estimation of equation (7.1) and subsequent tests for $y \in \{\pi, x, i\}$

No.	z_t / s_t	$CSGIRF_p^M(\pi)$			$CSGIRF_p^M(x)$			$CSGIRF_p^M(i)$		
		α^- v. α^+	β^- v. β^+	$\beta^\mp$ v. 0	α^- v. α^+	β^- v. β^+	$\beta^\mp$ v. 0	α^- v. α^+	β^- v. β^+	$\beta^\mp$ v. 0
1	x_{t-1}	-	-	$\beta^\mp < 0$	-	-	$\beta^\mp < 0$	-	-	$\beta^\mp < 0$
2	x_{t-1}^{SM}	-	-	$\beta^\mp > 0$	-	-	$\beta^\mp > 0$	-	-	$\beta^+ > 0$
3	i_{t-1}^{SM}	-	$\beta^- > \beta^+$	$\beta^\mp > 0$	-	$\beta^- < \beta^+$	$\beta^\mp < 0$	-	$\beta^- > \beta^+$	$\beta^+ > 0$
4	x_{t-1}^{SV}	-	-	$\beta^\mp > 0$	-	-	$\beta^\mp > 0$	-	-	$\beta^\mp < 0$

The exercise performed here reveals that no model implies significant sign asymmetries with respect to average effects of positive and negative monetary shocks (α^- v. α^+), and only one model (no. 3) delivers a different linear reaction of $CSGIRF_p^M(y)$ to positive and negative interest rate shocks.

As far as size asymmetry is concerned, the detected patterns of inequalities between $\beta^\mp$ and 0 are also very mixed:

- for $CSGIRF_p^M(\pi)$ all models predict size asymmetry – in 3 cases the detected relation is positive, while in 1 case it is negative
- for $CSGIRF_p^M(x)$ all models predict size asymmetry – in 2 cases the detected relation is positive, while in 2 cases it is negative
- for $CSGIRF_p^M(i)$ all models predict size asymmetry – in 2 cases the detected relation is positive, while in 2 cases it is negative.

The results obtained here do not allow us to come to a final conclusion that sign and size asymmetries are prevalent features of monetary transmission, as only one model detects significant sign asymmetry. On the contrary, all of the models pointed to significant size asymmetries, but there was no consensus whether the relation was positive or negative. We claim, therefore, that the existence of sign and size asymmetries of the effects of interest rate shocks on model variables is dubious. Before drawing final conclusions, however, we also analyse the behaviour of ratios of effectiveness and efficiency of monetary policy shocks for which patterns of asymmetry could be potentially more robust.

7.2.3 Effectiveness and efficiency of the discretionary monetary policy

From the monetary policy perspective an analysis of sign and size asymmetry should take into account that the interest rate is a policy variable which remains under the control of a central bank. Therefore, the monetary authorities might be interested in relative measures of response of inflation and the output gap as compared to response of the interest rate to monetary policy shock. We propose two such measures (one with respect to inflation and one with respect to the output gap), which we call measures of effectiveness of the discretionary monetary policy:

$$Effectiveness(\pi) = CSGIRF_p^M(\pi)/CSGIRF_p^M(i)$$

$$Effectiveness(x) = CSGIRF_p^M(x)/CSGIRF_p^M(i)$$

Because the proposed measures are in fact ratios which standardise the response of inflation and the output gap with respect to the response of interest rate shock, one may expect that the patterns of sign and size asymmetries could be different (e.g. more robust) than the ones presented in the previous paragraph.

Since the monetary authorities are usually interested in either lowering inflation at a possibly low output cost or boosting the economy at a possibly low inflation cost, we also propose a simple ratio of efficiency of the discretionary monetary policy[71].

$$Efficiency = CSGIRF_p^M(x)/CSGIRF_p^M(\pi)$$

Intuitively, central bankers would usually like to maximise the proposed ratio when loosening the monetary conditions and to minimise it when tightening the monetary conditions.

Just as in the case of measures of effectiveness of the discretionary monetary policy, standardisation of the response of output with respect to the response of inflation to interest rate shock is theoretically potent to deliver qualitatively different patterns of sign and size asymmetries from those observed in the previous paragraph.

Similarly as before, we perform the analysis of sign and size asymmetries on the basis of regressions in the spirit of (7.1) and subsequent tests, where $CSGIRF_p^M(y)$ is substituted with the proposed measures of effectiveness and efficiency of the discretionary monetary policy. Table 7.3 presents the summary findings, while more detailed regression outputs are available in Tables A8.4 – A8.6 in Appendix A8.

[71] If someone is a proponent of the monetarists' view that 'inflation is always and everywhere a monetary phenomenon' or treats inflation as a policy variable, the proposed ratio might be seen as another measure of effectiveness of the monetary policy.

Table 7.3 Summary results of estimation of equation (7.1) and subsequent tests for the proposed measures of effectiveness and efficiency of discretionary monetary policy.

No.	z_t / s_t	$Effectiveness(\pi)$			$Effectiveness(x)$			$Efficiency$		
		α^- v. α^+	β^- v. β^+	$\beta^\mp$ v. 0	α^- v. α^+	β^- v. β^+	$\beta^\mp$ v. 0	α^- v. α^+	β^- v. β^+	$\beta^\mp$ v. 0
1	x_{t-1}	-	-	$\beta^\mp < 0$	-	-	$\beta^\mp < 0$	-	-	$\beta^\mp < 0$
2	x_{t-1}^{SM}	-	-	$\beta^\mp > 0$	-	-	$\beta^\mp > 0$	-	-	$\beta^\mp > 0$
3	i_{t-1}^{SM}	-	$\beta^- > \beta^+$	-	-	$\beta^- < \beta^+$	$\beta^\mp < 0$	-	$\beta^- < \beta^+$	$\beta^\mp < 0$
4	x_{t-1}^{SV}	-	-	$\beta^\mp > 0$	-	-	$\beta^\mp > 0$	-	-	$\beta^\mp > 0$

The patterns we observe in Table 7.3 are qualitatively very similar to those in Table 7.2. Despite the standardisation, the results of sign and size asymmetries for the proposed ratios are still far from being robust. As previously, we interpret such an outcome as a lack of empirical support for the existence of strong sign and asymmetries of monetary transmission.

7.2.4 Asymmetric risk and structural uncertainty

Official FOMC statements and minutes reveal that the monetary authorities' decisions are based not only on expected paths of the economy under considered scenarios, but also on a balance of risks or uncertainties regarding possible policy actions. As was already discussed in subsections 1.7, nonlinearity of the model implies an inherent uncertainty of monetary transmission, even if the true model and its parameters are known; this is a feature which is not shared by linear models. Therefore, nonlinear models of the monetary transmission mechanism serve as natural workhorses for analysing the risks and uncertainties of monetary impulse propagation. Bearing in mind the scope of this thesis, we are particularly interested in investigating the asymmetry of monetary transmission risk, which is the reason for which we define $CSGIRF_p^{Sk}(y)$:

$$CSGIRF_{t,p}^{Sk}(y) = \begin{cases} \frac{CSGIRF_{t,p}^{P95}(y) - CSGIRF_{t,p}^{M}(y)}{CSGIRF_{t,p}^{M}(y) - CSGIRF_{t,p}^{P5}(y)} - 1 & if \quad \frac{CSGIRF_{t,p}^{P95}(y) - CSGIRF_{t,p}^{M}(y)}{CSGIRF_{t,p}^{M}(y) - CSGIRF_{t,p}^{P5}(y)} \geq 1 \\ -\frac{CSGIRF_{t,p}^{M}(y) - CSGIRF_{t,p}^{P5}(y)}{CSGIRF_{t,p}^{P95}(y) - CSGIRF_{t,p}^{M}(y)} + 1 & if \quad \frac{CSGIRF_{t,p}^{P95}(y) - CSGIRF_{t,p}^{M}(y)}{CSGIRF_{t,p}^{M}(y) - CSGIRF_{t,p}^{P5}(y)} < 1 \end{cases}$$

The proposed measure captures the relative asymmetry between the 95^{th} and 5^{th} percentile and it is standardised as to be symmetric with respect to 0. If the measure is above 0, the distribution of (cumulative standardised) impulse responses has a positive skew, which might be perceived as an upward risk for the path of the impulse response. Although the median implies that both positive and negative deviations are equally probable – the positive deviations are expected to be larger than the negative ones once they happen.

Analogously as in the previous paragraph, we perform an analysis of the sign and size asymmetry of $CSGIRF_p^{Sk}(y)$ on the basis of equation (7.1), in which we substitute $CSGIRF_p^{M}(y)$ with $CSGIRF_p^{Sk}(y)$. In this case, however, we slightly modify the set of verified hypotheses in order to take into account that $CSGIRF_p^{Sk}(y)$ is a measure of the asymmetry itself – by using the Wald test we test two main and four auxiliary null hypotheses:

1. $H_0^1\colon \alpha^- = \alpha^+ = 0$
    a. $H_0^{1a}\colon \alpha^- = \alpha^+$
    b. $H_0^{1b}\colon \alpha^- = -\alpha^+$
2. $H_0^2\colon\ \beta^- = \beta^+ = 0$
    a. $H_0^{2a}\colon \beta^- = \beta^+$
    b. $H_0^{2b}\colon \beta^- = -\beta^+$

In H_0^1 we test whether the distribution of (cumulative standardised) impulse responses has a non-zero skew, while in H_0^{1a} and H_0^{1b} we check if the skew has the same absolute value for positive and negative interest rate shocks (sign asymmetry). Analogously, in H_0^2, H_0^{2a} and H_0^{2b} we test whether the skew depends on the size of the shock (size asymmetry) and, if yes, whether the linear function is odd or even with respect to monetary shocks (size and sign asymmetries).

Tables 7.4 – 7.6 present the summary findings based on the presented method of analysis. More detailed results are available in Tables A8.7 – A8.10 in Appendix 8.

Table 7.4 Summary results of estimation of equation (7.1) and corresponding tests for $CSGIRF_p^{Sk}(\pi)$

No.	z_t / s_t	$\lvert\alpha^-\rvert$ v. $\lvert\alpha^+\rvert$	$\alpha^\mp$ v. 0	$\lvert\beta^-\rvert$ v. $\lvert\beta^+\rvert$	$\beta^\mp$ v. 0	$Mean$	$Median$
1	x_{t-1}	$\alpha^- = -\alpha^+$	$\alpha^- > 0, \alpha^+ < 0$	$\beta^- = \beta^+$	$\beta^\mp < 0$	0.017	-1.381
2	x_{t-1}^{SM}	$\lvert\alpha^-\rvert > \lvert\alpha^+\rvert$	$\alpha^- > 0, \alpha^+ < 0$	$\lvert\beta^-\rvert < \lvert\beta^+\rvert$	$\beta^- > 0, \beta^+ < 0$	-0.177	-3.219
3	i_{t-1}^{SM}	$\alpha^- = -\alpha^+$	$\alpha^- < 0, \alpha^+ > 0$	$\beta^- = \beta^+$	$\beta^\mp > 0$	0.139	1.180
4	x_{t-1}^{SV}	$\alpha^- = -\alpha^+$	$\alpha^- < 0, \alpha^+ > 0$	$\beta^- = -\beta^+$	$\beta^- < 0, \beta^+ > 0$	0.085	2.496

Table 7.5 Summary results of estimation of equation (7.1) and corresponding tests for $CSGIRF_p^{Sk}(x)$

No.	z_t / s_t	$\|\alpha^-\|$ v. $\|\alpha^+\|$	$\alpha^\mp$ v. 0	$\|\beta^-\|$ v. $\|\beta^+\|$	$\beta^\mp$ v. 0	$Mean$	$Median$
1	x_{t-1}	$\|\alpha^-\| > \|\alpha^+\|$	$\alpha^- > 0, \alpha^+ < 0$	$\|\beta^-\| = \|\beta^+\|$	$\beta^\mp = 0$	0.188	-1.209
2	x_{t-1}^{SM}	$\|\alpha^-\| > \|\alpha^+\|$	$\alpha^- > 0, \alpha^+ < 0$	$\|\beta^-\| < \|\beta^+\|$	$\beta^+ < 0$	-0.209	-3.701
3	i_{t-1}^{SM}	$\|\alpha^-\| > \|\alpha^+\|$	$\alpha^- > 0, \alpha^+ < 0$	$\|\beta^-\| < \|\beta^+\|$	$\beta^\mp < 0$	-0.374	-2.681
4	x_{t-1}^{SV}	$\alpha^- = \alpha^+$	$\alpha^- < 0, \alpha^+ > 0$	$\beta^- = -\beta^+$	$\beta^- < 0, \beta^+ > 0$	0.078	2.241

Table 7.6 Summary results of estimation of equation (7.1) and corresponding tests for $CSGIRF_p^{Sk}(i)$

No.	z_t / s_t	$\|\alpha^-\|$ v. $\|\alpha^+\|$	$\alpha^\mp$ v. 0	$\|\beta^-\|$ v. $\|\beta^+\|$	$\beta^\mp$ v. 0	$Mean$	$Median$
1	x_{t-1}	$\alpha^- = -\alpha^+$	$\alpha^- > 0$	$\|\beta^-\| = \|\beta^+\|$	$\beta^\mp = 0$	0.445	-1.189
2	x_{t-1}^{SM}	$\|\alpha^-\| > \|\alpha^+\|$	$\alpha^- > 0, \alpha^+ < 0$	$\|\beta^-\| < \|\beta^+\|$	$\beta^- > 0, \beta^+ < 0$	-0.191	-3.453
3	i_{t-1}^{SM}	$\|\alpha^-\| < \|\alpha^+\|$	$\alpha^- < 0, \alpha^+ > 0$	$\|\beta^-\| < \|\beta^+\|$	$\beta^\mp > 0$	0.112	0.429
4	x_{t-1}^{SV}	$\|\alpha^-\| > \|\alpha^+\|$	$\alpha^- > 0, \alpha^+ < 0$	$\beta^- = -\beta^+$	$\beta^- > 0, \beta^+ < 0$	-0.072	-2.315

Similarly as before, a very profound lack of robustness does not allow to point to any distinctive patterns of sign and size asymmetries. What is more, the obtained results are ambiguous even if the sign of the skew of distribution of (cumulative standardised) impulse responses is concerned. Some models suggest that the average or median risk for the impulse responses of a particular model variable is positive, while other models contradict this statement and induce the opposite view. In our opinion, such a strong discrepancy should be perceived as a lack of empirical support for the existence of sign and size asymmetries. In the following paragraph, in which we present general conclusions from the analysis of sign and size asymmetries, we elaborate on this issue in greater detail.

7.2.5 General conclusions from the analysis of sign and size asymmetries

We believe that the most important conclusion which can be drawn from the analysis of sign and size asymmetries of the (cumulative standardised) impulse responses presented here is that the results are highly dependent on the employed transition variable. As we have already mentioned, size and sign asymmetries are to a great extent the by-products of the nonlinear function being used and, manifestly, the adopted framework is not potent to solve, in this context, the problem of identification.

Taking the above into consideration, it comes as no surprise that empirical evidence for sign and size asymmetries is mixed (see Table A1.5 in Appendix A.1) in the literature. Of the 6 analysed studies which discussed the problem of sign or size asymmetries, 3 were based on threshold VAR models; 2 were based on smooth transition $VECM$ or VAR models and 1 on nonparametric propensity score weighting. Since any threshold model may be perceived as a restricted smooth transition model, at least 5 of the 6 analysed studies may be flawed with a profound lack of robustness with respect to the choice of threshold/transition variable. The problem is even more serious if we acknowledge that some inconclusive or frail results or studies may not have been published due to research and publications biases.

As was already stated in the previous paragraphs, we claim that the observed lack of robustness does not allow one to support the view that distinctive sign and size asymmetries are prevalent features of monetary transmission. Nevertheless, a statement that the sign and size asymmetries are, according to our research, non-existent would be abusive, since obviously the 'absence of evidence is not evidence of absence'.

The analysis conducted here reveals that a successful investigation of the problem of sign and size asymmetries of monetary transmission should probably be based on a framework that allows for precise identification of the impulse propagation mechanism itself rather than on identification of a model (treated as a system of structural equations linking the endogenous variables) which later gives rise to impulse responses. Estimation based on propensity score weighting which was proposed by Angrist, Jordà, and Kuersteiner (2013) seems to be a very promising tool in that context.

7.3 State asymmetry

7.3.1 The method

The analysis of state asymmetry of monetary transmission is based on the generalised impulse response functions derived from the $STAR$ models as presented in subsections 6.3 (modelling nonlinearity), 6.4 (modelling indirect forms of nonlinearity) and 6.5 (modelling state-dependency).

In the case of the $STAR$ model from subsection 6.3 (modelling nonlinearity) and 3 $STAR$ models from subsection 6.4 (modelling indirect forms of nonlinearity), generalised impulse response functions are calculated by using stochastic simulations with 100000 repetitions and the bootstrap technique, according to which the innovations are drawn (in triplets) randomly, with replacement from the model residuals assuming the empirical covariance matrix.

For each observation in a sample, a model is treated with an interest rate shock equal to the mean squared residual from a relevant interest rate equation, while the actual values of the models' variables serve as a data environment for impulse propagation. Again, the method of deriving generalised impulse response functions is designed to employ only the estimation sample and data which could have been 'seen' by the model – the aim of such a procedure is to avoid problems as were raised by the Lucas critique (1976).

As a result of the exercises described here, for each model, model variable and point in time when the shock is initialised, we obtain a density of 100000 generalised impulse response functions:

$$\boldsymbol{GIRF}_{t+h}\left(y, \hat{v}_{i,t}, \Omega_t\right) = E\left\{y_{t+h} \middle| \hat{v}_{i,t}, \Omega_t\right\} - E\{y_{t+h}|\Omega_t\}, \qquad h \in \mathbb{N}^+$$

After standardisation and summing over 16 periods, we track the median of the obtained distribution only:

$$\boldsymbol{SGIRF}_{t+h}(y, \Omega_t) = \frac{\boldsymbol{GIRF}_{t+h}\left(y, \hat{v}_{i,t}, \Omega_t\right)}{\hat{v}_{i,t}}, \qquad h \in \mathbb{N}^+$$

$$\boldsymbol{CSGIRF}_t(y, \Omega_t) = \sum_{h=0}^{16} \boldsymbol{SGIRF}_{t+h}(y, \Omega_t)$$

$$CSGIRF_t^M(y, \Omega_t) = Median\left(\boldsymbol{CSGIRF}_t(y, \Omega_t)\right)$$

In the case of all $STAR$ models from subsection 6.5 (modelling state-dependency), the values of transition variables are unaffected by the values of endogenous variables. Therefore, we use a deterministic solution to calculate the impulse response functions to unitary shock[72] for each observation in a sample. Similarly as before, the actual values of the models' variables serve as a data environment for impulse propagation. We obtain a standardised impulse response function, which after summing over 16 periods gives rise to a cumulative standardised impulse response function:

$$SIRF_{t+h}(y, \Omega_t) = E\left\{y_{t+h} \middle| \hat{v}_{i,t} = 1, \Omega_t\right\} - E\left\{y_{t+h} \middle| \hat{v}_{i,t} = 0, \Omega_t\right\}, \qquad h \in \mathbb{N}^+$$

[72] In the analysed models the impulse response functions are always proportional to the size of the initial shock. Therefore, setting the size of a shock to 1 is equivalent to standardisation of the impulse response function.

$$CSIRF_t(y, \Omega_t) = \sum_{h=0}^{16} SIRF_{t+h}(y, \Omega_t)$$

The two measures, $CSGIRF_t^M(y, \Omega_t)$ and $CSIRF_t(y, \Omega_t)$, are equivalent – for any model which is solved deterministically we can also calculate $CSGIRF_t^M(y, \Omega_t)$ by solving the model stochastically, and then $CSGIRF_t^M(y, \Omega_t)$ approaches $CSIRF_t(y, \Omega_t)$ as the number of repetitions goes to infinity. Therefore, in order to unify and simplify the notation we use $CSGIRF_t^M(y, \Omega_t)$ to also denote $CSIRF_t(y, \Omega_t)$.

Analogously as in the previous subsection, we are interested in the following 6 measures describing monetary transmission[73]:

- $CSGIRF_t^M(\pi, \Omega_t)$
- $CSGIRF_t^M(x, \Omega_t)$
- $CSGIRF_t^M(i, \Omega_t)$
- $Effectiveness_t(\pi, \Omega_t) = CSGIRF_t^M(\pi, \Omega_t)/CSGIRF_t^M(i, \Omega_t)$
- $Effectiveness_t(x, \Omega_t) = CSGIRF_t^M(x, \Omega_t)/CSGIRF_t^M(i, \Omega_t)$
- $Efficiency_t(\Omega_t) = CSGIRF_t^M(x, \Omega_t)/CSGIRF_t^M(\pi, \Omega_t)$

The idea behind the analysis performed in the subsequent paragraphs is to check what the relation is between the proposed 6 measures and the relevant ‘nonlinear’ or ‘state’ transition variable with respect to which a particular $STAR$ model was estimated. Bearing in mind that such a relation might be very complex, we are interested in whether it is generally positive or negative. Therefore, we estimate a sequence of the following simple equations[74]:

$$Measure_t = \alpha + \beta \frac{\sum_{h=0}^{16} s_{t+h}}{16} + \varepsilon \qquad (7.2)$$

$Measure_t$ denotes any of the above-mentioned 6 measures characterising monetary transmission, while s_t is the relevant ‘nonlinear’ or ‘state’ transition variable (we are interested in the mean value of s_t over 16 quarters which corresponds to the time horizon over which we cumulate the impulse responses).

[73] Here we do not analyse asymmetric risk because the measure $CSGIRF_t^{Sk}(y, \Omega_t)$ is not applicable for models which do not require a stochastic solution.

[74] In each case we have 55 observations – the total size of a sample is 71 observations, but 16 observations are ‘consumed’ for calculating cumulative impulse responses.

In the subsequent paragraphs we present the estimates of β and the p-value of a simple t-test for statistical significance and we discuss the obtained results. We start from state asymmetry with respect to model variables (7.3.2), while later the sequence is the same as when we were testing and modelling state-dependency of the monetary transmission mechanism.

7.3.2 State asymmetry with respect to model variables

In this paragraph we check whether values of model variables during monetary impulse propagation have an influence on what monetary transmission looks like. Table 7.7 presents models which were used for the analysis of state asymmetry with respect to model variables, while Table 7.8 shows the relevant results of estimation of equations (7.2). Figure A9.1 in Appendix A.9 allows for a simple eyeball test.

Table 7.7 Models of the monetary transmission mechanism employed for the analysis of state asymmetry with respect to the selected model variables

No.	z_t / s_t	inflation equation	output gap equation	interest rate equation
1	x_{t-1}	$LINEAR$	$LSTAR1$	$LINEAR$
2	x_{t-1}^{SM}	$LINEAR$	$LSTAR1$	$LINEAR$
3	i_{t-1}^{SM}	$LSTAR1$	$LINEAR$	$LINEAR$
4	x_{t-1}^{SV}	$LINEAR$	$LINEAR$	$LSTAR1$

Table 7.8 The results of estimation of equations (7.2) for the selected model variables

No.	z_t / s_t	$CSGIRF_t^M(\pi,\Omega_t)$	$CSGIRF_t^M(x,\Omega_t)$	$CSGIRF_t^M(i,\Omega_t)$	$Effectiv(\pi,\Omega_t)$	$Effectiv(x,\Omega_t)$	$Efficien(\Omega_t)$
1	x_{t-1}	-0.037 [0.000]	-0.176 [0.000]	-0.153 [0.000]	-0.044 [0.000]	-0.109 [0.000]	0.126 [0.000]
2	x_{t-1}^{SM}	-0.017 [0.001]	-0.092 [0.002]	-0.072 [0.002]	-0.027 [0.000]	-0.074 [0.000]	0.057 [0.005]
3	i_{t-1}^{SM}	0.851 [0.000]	-0.376 [0.000]	0.911 [0.000]	0.077 [0.000]	-0.020 [0.000]	0.155 [0.647]
4	x_{t-1}^{SV}	-0.015 [0.005]	-0.009 [0.005]	0.062 [0.004]	0.000 [0.003]	0.000 [0.006]	0.001 [0.003]

The estimates for nos. 1 and 2 supply robust evidence that the response of all model variables to the monetary policy shock is smaller when the average value of the output gap is high, i.e. when the economy is in a boom period. A similar pattern is observed after standardisation against the interest rate – effectiveness of the monetary policy with respect to inflation and the output gap is significantly smaller when the economy is overheated. At the same time, efficiency of the monetary policy is higher when the output gap is positive than when it is negative. Such results are consistent with the findings presented in paragraph 2.3.3 and subsection 2.5.

If we look at variance of the output gap (no. 4) instead of at its average level, there is evidence that the response of the output gap and inflation is smaller, while the efficiency of the monetary policy is larger when the output gap is more volatile.

As far as state asymmetry with respect to the interest rate is concerned, the results for no. 3 suggest that monetary shocks have bigger effects on inflation and the interest rate when the level of the latter variable is high. The opposite is true for the output gap. The patterns of effectiveness of the monetary policy are similar – there exists a positive relation between the level of the interest rate and the effectiveness of the monetary policy with respect to inflation, while the opposite relation holds for the effectiveness of the monetary policy with respect to the output gap. Model no. 3 implies no such relation for the efficiency of the monetary policy.

The results obtained here, taken together, suggest that the monetary policy may find it difficult to conduct disinflation when the economy is overheated since the sacrifice ratio is positively related to the level of the output gap.Therefore, the monetary authorities may have some incentives not to fight the boom but rather to wait until it is over and to drag the inflation down opportunistically when the economy is on the slide. By the same token, when the economy is in the doldrums, inflation remains relatively irresponsive to changes in the output gap.

7.3.3 State asymmetry with respect to measures of business cycle and climate

Here we verify and discuss the relations between the six measures describing monetary transmission and the selected measures of business cycle and climate which were found to yield $STAR$ models that are preferred over the linear baselines. Analogously as in the previous paragraph, Table 7.9 presents the models employed here, Table 7.10 reveals the results of estimation of equations (7.2), while Figure A9.2 in Appendix A.9 plots the investigated relations.

According to the obtained estimates, the higher the capacity utilisation (no. 1), the higher the inflation response to monetary shock and the smaller the response of the interest rate. Capacity utilisation is positively related to the effectiveness of the monetary policy with respect to the output gap but negatively related with the efficiency of the monetary policy. Such results may strike as being somewhat ambiguous when compared with those from the previous paragraph because both capacity utilisation and the output gap may be perceived as measures of slack in the economy. It is, however, important to recall that all 'state' transition variables were orthogonalised with respect to the model variables. Therefore, a high level of (orthogonalised) capacity utilisation may signal low supply rather than high demand. Moreover, the diagnostic tests revealed that the $STAR$ model of the output gap, in which capacity utilisation is a transition variable, suffers from the problem of an incorrect functional form at a 1% significance level. Therefore, the obtained patterns of impulse responses should be treated with caution.

Table 7.9 Models of the monetary transmission mechanism employed for the analysis of state asymmetry with respect to the selected measures of business cycle and climate

No.	s_t	Short data description	inflation equation	output gap equation	interest rate equation
1	cu_t	Capacity utilization	$LINEAR$	$LSTAR1$	$LSTAR1$
2	ai_ma_t	Chicago Fed National Activity Index: three month moving average	$LINEAR$	$ESTAR$	$LSTAR1$
3	ai_di_t	Chicago Fed National Activity Index: diffusion index	$LINEAR$	$LSTAR1$	$LSTAR1$
4	cs_t	University of Michigan: Consumer Sentiment Index©	$LINEAR$	$LSTAR1$	$LINEAR$

Table 7.10 The results of estimation of equations (7.2) for the selected measures of business cycle and climate

No.	s_t	$CSGIRF_t^M(\pi,\Omega_t)$	$CSGIRF_t^M(x,\Omega_t)$	$CSGIRF_t^M(i,\Omega_t)$	$Effectiv(\pi,\Omega_t)$	$Effectiv(x,\Omega_t)$	$Efficien(\Omega_t)$
1	cu_t	0.035 [0.000]	0.004 [0.811]	-0.369 [0.000]	0.000 [0.512]	0.006 [0.000]	-0.061 [0.000]
2	ai_ma_t	-0.252 [0.000]	-1.607 [0.000]	-0.868 [0.000]	-0.033 [0.000]	-0.131 [0.000]	1.107 [0.000]
3	ai_di_t	-0.269 [0.000]	-3.093 [0.000]	-3.641 [0.000]	-0.082 [0.000]	-0.267 [0.000]	2.493 [0.000]
4	cs_t	-0.016 [0.000]	-0.047 [0.000]	0.030 [0.000]	-0.002 [0.000]	-0.009 [0.000]	0.038 [0.000]

Although nos. 2, 3 and 4 give contradictory results when the response of the interest rate is concerned, they very robustly show that inflation and output gap responses and effectiveness of the monetary policy with respect to those variables are negatively related to the business climate. At the same time, corresponding relations for the efficiency of the monetary policy are positive. Such findings are consistent with those obtained in the previous paragraph when the output gap or its average level was treated as a transition variable.

7.3.4 State asymmetry with respect to measures of labour market conditions

In this paragraph we test for state asymmetry of monetary transmission with respect to selected measures of labour market conditions. Table 7.11 reveals the models employed for the analysis and Table 7.12 shows the results of estimation of equations (7.2). The plots are available in Appendix A.9 (Figure A9.3).

According to the test performed here, all measures describing the monetary transmission mechanism, apart from the efficiency of the monetary policy (statistically insignificant relation), are positively related to the dynamics of wages and salaries. In other words, the monetary policy is more effective at influencing inflation and the output gap when compensation growth is high. Such a result is observed due to state-dependency of the output gap equation and might be justified in the spirit of *cumulative prospect theory* – when growth of wages and salaries is low, any negative monetary shock may force consumers to reach their downward reference point. For a short period of time this constraint is binding because consumers have a strong aversion against consuming less than their reference point and, therefore, a restrictive monetary policy is temporarily ineffective at lowering consumption. In contrast, when growth of compensation is high, both positive and negative monetary shocks are effective because consumption is far above the temporarily binding constraint.

Surprisingly, the patterns presented here are not shared by the model of monetary transmission in which the Labour Market Conditions Index is a transition variable. In this case, relations for the response of the interest rate and both measures of effectiveness of the monetary policy have an opposite sign. It is, however, important to recall that the $LSTAR1$ output gap equation was diagnosed (see Table 6.7) as suffering from an incorrect functional form, which should induce us to look at the obtained results with the utmost caution. Moreover, construction of the index[75] reveals that it mainly correlates with measures of employment and unemployment, not compensation. Then, lower effectiveness of the monetary policy with respect to inflation and the output gap may result from difficulties in boosting the economy when it is close to full employment, i.e. when unemployment has a structural or frictional nature.

[75] see http://www.federalreserve.gov/econresdata/notes/feds-notes/2014/assessing-the-change-in-labor-market-conditions-20140522.html

Table 7.11 Models of the monetary transmission mechanism employed for the analysis of state asymmetry with respect to the selected measures of labour market conditions

No.	s_t	short data description	inflation equation	output gap equation	interest rate equation
1	$w\&s_t$	Compensation of employees: wages and salaries, annualised percent change from quarter ago	$LINEAR$	$LSTAR1$	$LINEAR$
2	$lmci_t$	Labour Market Conditions Index	$LINEAR$	$LSTAR1$	$LSTAR1$

Table 7.12 The results of estimation of equations (7.2) for the selected measures of labour market conditions

No.	s_t	$CSGIRF_t^M(\pi,\Omega_t)$	$CSGIRF_t^M(x,\Omega_t)$	$CSGIRF_t^M(i,\Omega_t)$	$Effectiv(\pi,\Omega_t)$	$Effectiv(x,\Omega_t)$	$Efficien(\Omega_t)$
1	$w\&s_t$	0.085 [0.000]	0.173 [0.000]	0.140 [0.000]	0.028 [0.000]	0.068 [0.000]	3.097 [0.674]
2	$lmci_t$	0.191 [0.000]	0.077 [0.000]	-1.378 [0.000]	-0.007 [0.000]	-0.003 [0.000]	0.001 [0.000]

7.3.5 State asymmetry with respect to measures of financial conditions

The current paragraph deals with the problem of state asymmetry of monetary transmission with respect to selected measures of financial conditions. Analogously as in the previous paragraphs, the models, estimation results and corresponding graphs employed here are presented in Table 7.13, Table 7.14, and Figure A9.4 (Appendix A.9), respectively.

Indices of financial conditions

The detected patterns of state asymmetry of monetary transmission vary for different indices of financial conditions. The most distinctive result is obtained when the Chicago Fed National Financial Conditions Leverage Subindex serves as a transition variable (no. 2) – the responses of all model variables are negatively related to the level of this subindex (but estimates for both measures of effectiveness and efficiency of the monetary policy are statistically insignificant). At the same time, the other three indices predict the opposite relation for responses of the output gap and the interest rate, while there is no consensus among them if the response of inflation and effectiveness of the monetary policy with respect to inflation is concerned.

We believe that the main source of discrepancy between the CFNFC Leverage Subindex and the other indices is due to the fact that the CFNFC Leverage Subindex is a proxy of financial conditions on debt and the stock market, i.e. markets which are partially substitutive for the money and credit market. Bearing in mind that all transition variables were orthogonalised against the model variables, the high value of the Leverage Subindex may reflect relatively easy access to funds from debt and stock markets. Then, enterprises or financial institutions would be relatively less interested in funds from money and credit markets, i.e. a main channel through which changes in interest rates are transmitted into the real economy. Therefore, the response of all model variables would be lower than when the value of the Leverage Subindex is small. It is also worth noting that the obtained estimates of both measures of effectiveness of the monetary policy are negative, which is consistent with the proposed explanation and *credit channel theory*, while the lack of statistical significance is due to one large outlier (see no. 2 in Figure A7.4)

On the other hand, the CredAbility Consumer Distress Index (no. 1) and the Chicago Fed National Financial Conditions Credit Subindex (no. 3) measure relative access to credit markets – the bigger the values of the indices, the better the access and, in consequence, the more enterprises, consumers or financial institutions could be affected by changes in the interest rates. Therefore, responses of model variables and effectiveness of the monetary policy are positively related to the values of the indices, which is in line with the findings of *credit channel theory*. Model no. 1 additionally suggests a negative relation between the efficiency of the monetary policy and the index value (no such finding for model no. 3), which means that easy access to credit markets facilitates relatively 'painless' disinflation and should dishearten the monetary authorities from conducting an expansionary policy due to high costs in terms of raising inflation. In the end, it is, however, important to remember that the $LSTAR1$ interest rate equation where the CredAbility Consumer Distress Index is a transition variable was diagnosed as suffering from an incorrect functional form, thus the results obtained for that variable should be treated very carefully.

The Chicago Fed National Financial Conditions Risk Subindex is the only transition variable among the selected measures of financial conditions which was found to be important for the inflation equation. Therefore, the estimated relations between the six measures characterising monetary transmission and the index should be interpreted in the spirit of the theories presented in paragraph 2.2.2 – we find *rational inattention* models to be particularly useful in this context. The CFNFC Risk Subindex is designed to capture 'volatility and funding risk in the financial sector'. Thus it may be perceived as a variable influencing volatility of the output gap shocks. According to *rational inattention* models, increasing relative volatility of output gap shocks should result in raising the relative responsiveness of the output gap to nominal shocks, which is exactly the pattern we observe in the data. The response of the output gap and the effectiveness of the monetary policy with respect to the output gap are positively related to the CFNFC Risk Subindex, while the opposite is true for inflation.

Monetary aggregates

The analysis performed here shows that monetary base growth (no. 5) has a different impact on the considered measures characterising monetary transmission than MZM (no. 6) and M2 (no. 7). In particular, we find that high dynamics of the monetary base leads to lowering the effectiveness of the monetary policy with respect to both inflation and the output gap, while the opposite relation holds for MZM and M2.

A justification for this may be straightforward – the larger the monetary base, the larger the amount of money over which the central bank may use its leverage in the form of parameters regarding reserve requirements and the larger the money supply that can be potentially created (if there is enough demand for money funds), given the money multiplier. Therefore, the interest rate shock may operate effectively through the money demand channel while – in the case of some disturbances – the monetary authorities may adjust the parameters regarding reserve requirements as to achieve a desired level of money supply.

At the same time, the high dynamics of MZM or M2 may reflect a situation in which the money supply exceeds the level for which money demand is satisfied at a given level of the central bank's interest rate. Since not all financial institutions which are involved in money creation are eligible to borrow from or deposit in the central bank, some wedge between the market and the central bank's interest rate may emerge (at least in the case of financial institutions which are not the central bank's counterparties). Then interest rate shocks may be less effective in influencing inflation and the output gap due to an incomplete or sluggish interest rate pass-through in some market segments (see e.g. Cottarelli and Kourelis 1994).

Despite the aforementioned differences, it is worth emphasising that all of the three models predict a negative relation between growth of money aggregates and the efficiency of the expansionary monetary policy, and a positive relation between growth of money aggregates and the efficiency of the restrictionary monetary policy. Such a result gives additional incentives to stimulate the economy when it is constrained by low levels of the monetary base or money supply and conduct disinflation when money aggregates grow at high rate.

Quality of the credit portfolio

According to the estimates performed here, there is no clear relation between the characteristics of monetary transmission and the quality of the credit portfolio. On the one hand, such a result might be treated literally (as a lack of influence of credit portfolio quality on the shape of monetary transmission), while on the other hand it may be partially a consequence of the adopted conservative approach of modelling which included orthogonalisation of the transition variables. Once variation of credit portfolio quality due to changes in inflation, economic activity and interest rate is excluded, the variable may reflect the average conditions and selection procedure under which the credits were granted in the past. But since the transition variables were also detrended, only a small portion of variance remains unexplained. In consequence, even if the quality of the credit portfolio influences the shape of monetary transmission, the remnant part of a variable is not 'strong' enough to deliver statistically significant patterns of impulse responses.

Table 7.13 Models of the monetary transmission mechanism employed for the analysis of state asymmetry with respect to the selected measures of financial conditions

No.	s_t	short data description	inflation equation	output gap equation	interest rate equation
		Indices of financial conditions			
1	$ccdi_t$	CredAbility Consumer Distress Index	$LINEAR$	$ESTAR$	$LSTAR1$
2	$fcls_t$	Chicago Fed National Financial Conditions Leverage Subindex	$LINEAR$	$LSTAR1$	$LINEAR$
3	$fccs_t$	Chicago Fed National Financial Conditions Credit Subindex	$LINEAR$	$LSTAR1$	$LINEAR$
4	$fcrs_t$	Chicago Fed National Financial Conditions Risk Subindex	$LSTAR2$	$LINEAR$	$LINEAR$
		Monetary aggregates			
5	mb_t	Board of governors monetary base, annualised percent change from quarter ago	$LINEAR$	$LSTAR1$	$LINEAR$
6	mzm_t	MZM (money zero maturity) stock, annualised percent change from quarter ago	$LINEAR$	$LINEAR$	$LSTAR1$
7	$m2_t$	M2 money stock, annualised percent change from quarter ago	$LINEAR$	$LINEAR$	$LSTAR1$
		Quality of credit portfolio			
8	nl_tl_t	Nonperforming loans to total loans for all U.S. banks	$LINEAR$	$LSTAR1$	$LINEAR$
9	dr_t	Delinquency rate on all loans	$LINEAR$	$LSTAR1$	$LINEAR$

Table 7.14 The results of estimation of equations (7.2) for the selected measures of financial conditions

No.	s_t	$CSGIRF_t^M(\pi,\Omega_t)$	$CSGIRF_t^M(x,\Omega_t)$	$CSGIRF_t^M(i,\Omega_t)$	$Effectiv(\pi,\Omega_t)$	$Effectiv(x,\Omega_t)$	$Efficien(\Omega_t)$
				Indices of financial conditions			
1	$ccdi_t$	0.126 [0.000]	0.347 [0.000]	0.287 [0.000]	0.030 [0.000]	0.064 [0.001]	-0.309 [0.000]
2	$fcls_t$	-2.941 [0.005]	-13.477 [0.004]	-11.834 [0.004]	-7.483 [0.312]	-17.558 [0.312]	-100.783 [0.442]
3	$fccs_t$	0.438 [0.075]	9.023 [0.000]	6.651 [0.000]	0.133 [0.004]	1.300 [0.000]	24.558 [0.220]
4	$fcrs_t$	-1.955 [0.000]	0.671 [0.000]	0.035 [0.007]	-0.619 [0.000]	0.215 [0.000]	-5.683 [0.398]

Monetary aggregates							
5	mb_t	0.031 [0.364]	0.407 [0.000]	0.292 [0.000]	0.024 [0.019]	0.116 [0.000]	-0.628 [0.000]
6	mzm_t	0.048 [0.000]	0.032 [0.000]	-0.343 [0.000]	-0.003 [0.000]	-0.001 [0.000]	-0.002 [0.000]
7	$m2_t$	0.054 [0.000]	0.032 [0.000]	-0.260 [0.000]	-0.004 [0.000]	-0.001 [0.000]	-0.003 [0.000]
Quality of credit portfolio							
8	nl_tl_t	0.483 [0.401]	0.036 [0.941]	-0.124 [0.626]	0.025 [0.925]	0.266 [0.507]	-1.998 [0.037]
9	dr_t	0.404 [0.350]	-0.101 [0.844]	-0.171 [0.589]	0.134 [0.697]	-0.977 [0.725]	-0.811 [0.630]

7.3.6 State asymmetry with respect to measures of uncertainty

Here we verify and discuss state asymmetry of monetary transmission with respect to the two selected measures of uncertainty as were developed by Baker, Bloom and Davis (2013). Table 7.15 and Table 7.16 present the models employed here and the estimation results for equations (7.2) respectively, while Figure A9.5 (Appendix A.9) presents the analysed relationships.

We find that the empirical patterns of relationships between the six measures characterising monetary transmission and measures of uncertainty vary for different types of uncertainty, but in both cases state asymmetry of monetary transmission is caused by state-dependency of the output gap equation.

On the one hand, we find that responses of both inflation and the output gap as well as effectiveness of the monetary policy with respect to those variables are positively related with the level of economic policy uncertainty (no. 1). Such a result contrasts with Bloom's (2009) prediction that uncertainty shocks temporarily freeze propagation of the monetary (and fiscal) policy. Nevertheless, the observed pattern is explicable if we apply the *rational inattention models* framework (e.g. Maćkowiak and Wiederholt 2009, 2011) for the consumption-saving or investment-saving problems of economic agents. Optimising behaviour in the environment of the limited information-processing abilities of economic agents implies that they pay relatively more attention (and therefore are more reactive) to more volatile shocks. Since the interest rate is a monetary policy variable, the economic agents should be more reactive to changes in the interest rate if the monetary policy uncertainty is high. This is exactly the pattern we observe when the Economic Policy Uncertainty Index, which includes monetary policy uncertainty, is a transition variable.

On the other hand, *Bloom's concept on the role of uncertainty shocks* (Bloom 2009) is empirically consistent with our results if the Equity Market-Related Economic Uncertainty Index is treated as a transition variable in the monetary transmission model. Foremost, effectiveness of the monetary policy with respect to both inflation and the output gap is negatively related with the level of equity market-related uncertainty as was predicted by Bloom (2009). It is also worth emphasising that the obtained pattern may also be explained in the spirit of the *rational inattention models* framework similarly as above – if the equity market uncertainty goes up, the economic agents pay relatively more attention to equity market variables than to the monetary policy instrument. In consequence, the economic agents may become relatively less responsive to the latter.

Table 7.15 Models of the monetary transmission mechanism employed for the analysis of state asymmetry with respect to the selected measures of uncertainty

No.	s_t	short data description	inflation equation	output gap equation	interest rate equation
1	$epui_t$	Economic Policy Uncertainty Index for United States by Baker, Bloom and Davis (2013)	$LINEAR$	$LSTAR1$	$LINEAR$
2	$emeui_t$	Equity Market-related Economic Uncertainty Index by Baker, Bloom and Davis (2013)	$LINEAR$	$LSTAR1$	$LINEAR$

Table 7.16 The results of estimation of equations (7.2) for the selected measures of uncertainty

No.	s_t	$CSGIRF_t^M(\pi,\Omega_t)$	$CSGIRF_t^M(x,\Omega_t)$	$CSGIRF_t^M(i,\Omega_t)$	$Effectiv(\pi,\Omega_t)$	$Effectiv(x,\Omega_t)$	$Efficien(\Omega_t)$
1	$epui_t$	0.000 [0.001]	0.000 [0.046]	0.000 [0.600]	0.000 [0.001]	0.000 [0.024]	0.000 [0.253]
2	$emeui_t$	0.003 [0.000]	-0.000 [0.034]	-0.013 [0.000]	-0.000 [0.000]	-0.000 [0.000]	0.000 [0.000]

7.3.7 State asymmetry with respect to measures of globalisation

In this paragraph we deal with state asymmetry of monetary transmission with respect to selected measure of globalisation. Table 7.17, Table 7.18 and Figure A9.6 (Appendix A.9) present the models exploited here, the results of estimation of equations (7.2) and the relevant graphs, respectively.

World data

According to the obtained estimates, higher world economic growth (model no. 1) corresponds with lower responses of inflation and the output gap and lower effectiveness of the monetary policy with respect to those variables. At the same time, the opposite is true if the world export to world GDP ratio is a transition variable (model no. 3). It is, however, worth noting that state asymmetry of monetary transmission with respect to the two variables results purely from state-dependency of the interest rate equation (Table 7.17). In other words, although we find no support for state-dependency of either inflation or the output gap equation with respect to world GDP or world export to world GDP ratios, both variables seem to have been important information variables for the monetary policy which influenced the shape of monetary transmission in the Greenspan era.

In contrast to the two aforementioned variables, the world gross savings to world GDP ratio is a significant source of state-dependency of the output gap equation. We find that a larger value of this transition variable leads to higher responses of all model variables to interest rate shock, and in such a situation the effectiveness of the monetary policy with respect to inflation and the output gap is higher than for low values of world savings to world GDP ratio. Moreover, there exists a significant negative relation between the efficiency of the monetary policy and the level of world savings to world GDP ratio. The outcomes are at odds with fears that global liquidity may lower the Fed's leverage over the U.S. economy – the results are just the opposite. The larger the amount of global savings, the larger the amount of capital which reacts to changes in the federal funds rate, i.e. may be attracted (or repelled) to flow to the U.S. economy. Thus the effectiveness of the monetary policy gains from a larger amount of world savings. At the same time, the negative relation between the efficiency of the monetary policy and the level of the investigated ratio suggests that a high level of global savings should facilitate the disinflation policy and make it less costly. On the other hand, however, boosting the economy in such an environment may create additional inflationary pressure.

U.S. data

As far as data on the U.S. economy is concerned, we find that U.S. exports to U.S. GDP (real ratio) treated as a transition variable (no. 4) does not yield any significant relations with the six measures characterising monetary transmission. In contrast, we detect such relations if the U.S. balance on current account to U.S. GDP (nominal ratio) is a transition variable instead. In particular, we find that the response of inflation and the effectiveness of the monetary policy with respect to that variable are both lower for the current account surplus than for the current account deficit. Again we discover that globalisation, which is one of the factors blamed for the pre-crisis expansion of the U.S current account deficit, despite all the fears, leads to higher rather than lower effectiveness of the monetary policy, at least with respect to inflation (the estimates for the output gap are statistically insignificant). It is worth remembering that the current account deficit is accompanied by a financial and capital account surplus – therefore, the results presented here are consistent with results obtained when the world savings to world GDP ratio is a transition variable. Analogously as before, we find that a large current account deficit lowers the costs of disinflation but raises inflationary pressure when the monetary policy is expansionary.

Table 7.17 Models of the monetary transmission mechanism employed for the analysis of state asymmetry with respect to the selected measures of globalisation

No.	s_t	short data description	inflation equation	output gap equation	interest rate equation
		World data			
1	$wgdp_t$	World gross domestic product, constant 2005 dollar, annualised percent change from quarter ago	$LINEAR$	$LINEAR$	$LSTAR1$
2	ws_gdp_t	World gross savings, percent of world gross domestic product (nominal ratio)	$LINEAR$	$LSTAR1$	$LINEAR$
3	we_gdp_t	World exports of goods and services, percent of world gross domestic product, (nominal ratio)	$LINEAR$	$LINEAR$	$LSTAR1$
		U.S. data			
4	e_gdp_t	Real exports of goods and services, percent of real gross domestic product (real ratio)	$LINEAR$	$LINEAR$	$LSTAR2$
5	ca_gdp_t	Balance on current account, percent of gross domestic product (nominal ratio)	$LINEAR$	$ESTAR$	$LINEAR$

Table 7.18 The results of estimation of equations (7.2) for the selected measures of globalisation

No.	s_t	$CSGIRF_t^M(\pi,\Omega_t)$	$CSGIRF_t^M(x,\Omega_t)$	$CSGIRF_t^M(i,\Omega_t)$	$Effectiv(\pi,\Omega_t)$	$Effectiv(x,\Omega_t)$	$Efficien(\Omega_t)$
				World data			
1	$wgdp_t$	-0.844 [0.000]	-9.961 [0.000]	-13.436 [0.000]	-0.212 [0.000]	-0.599 [0.000]	48.378 [0.096]
2	ws_gdp_t	0.643 [0.000]	2.753 [0.000]	2.469 [0.000]	0.432 [0.000]	0.986 [0.000]	-2.830 [0.000]
3	we_gdp_t	3.988 [0.006]	15.448 [0.004]	0.904 [0.759]	0.652 [0.036]	2.456 [0.007]	16.032 [0.335]
				US data			
4	e_gdp_t	0.019 [0.417]	0.009 [0.403]	-0.063 [0.415]	-0.001 [0.557]	0.000 [0.875]	-0.001 [0.368]
5	ca_gdp_t	-18.339 [0.000]	0.581 [0.717]	-3.776 [0.002]	-5.296 [0.000]	0.248 [0.516]	19.543 [0.005]

7.3.8 State asymmetry with respect to measures of composition of the economy

The current paragraph is devoted to the problem of state asymmetry of monetary transmission with respect to the two selected measures of composition of the economy. Table 7.19 reveals the models employed here for the analysis, Table 7.20 presents the results of estimation of equations (7.2), while Figure A9.7 (Appendix A.9) plots the analysed relationships.

The two selected measures of the composition of the economy yield somewhat different conclusions as to the shape of monetary transmission, but in both cases state asymmetry is caused by state-dependency of the output gap equation.

We find that the level of labour share (model no. 1) is negatively related with the response of inflation but positively related with responses of the output gap and the interest rate to monetary shock. Most importantly, the effectiveness of the monetary policy with respect to the output gap is negatively related with labour share (an analogous relation for effectiveness with respect to inflation is statistically insignificant), which might be perceived as a natural consequence of the fact that capital is more responsive to interest rate than labour. The positive relation between labour share and efficiency implies that in an environment of high labour share the costs of disinflation are relatively high, while inflationary pressure caused by the expansionary policy is relatively low.

Different patterns emerge if the share of services in GDP (nominal ratio) is a transition variable (model no 2.) instead of labour share. Specifically, a larger share of services in GDP leads to higher responses of all model variables to interest rate shock and higher effectiveness of the monetary policy with respect to both inflation and the output gap. Although such a result may strike as being surprising because the share of services in GDP and the labour share are highly correlated (Pearson's coefficient equal to 77%), we believe that the obtained patterns may reflect the role of the financial sector (a part of the service sector), which is highly sensitive to changes in the interest rate. As far as the sacrifice/gain ratio is concerned, suggestions for the monetary policy are that lowering inflation is less costly when the share of services in GDP is high, while the expansionary monetary policy is more efficient when the share of services in GDP is low.

Table 7.19 Final model selection when modelling state-dependency with respect to the selected measures of composition of the economy

No.	s_t	short data description	inflation equation	output gap equation	interest rate equation
1	$lshare_t$	Labour share in nonfarm business sector	$LINEAR$	$LSTAR1$	$LINEAR$
2	sva_gdp_t	Services: value added: percent of gross domestic product (nominal ratio)	$LINEAR$	$LSTAR1$	$LINEAR$

Table 7.20 The results of estimation of equations (7.2) for the selected measures of composition of the economy

No.	s_t	$CSGIRF_t^M(\pi,\Omega_t)$	$CSGIRF_t^M(x,\Omega_t)$	$CSGIRF_t^M(i,\Omega_t)$	$Effectiv(\pi,\Omega_t)$	$Effectiv(x,\Omega_t)$	$Efficien(\Omega_t)$
1	$lshare_t$	-0.815 [0.000]	0.474 [0.000]	7.343 [0.000]	-0.001 [0.728]	-0.047 [0.000]	0.457 [0.000]
2	sva_gdp_t	0.176 [0.000]	1.237 [0.000]	0.847 [0.000]	0.121 [0.000]	0.394 [0.000]	-1.403 [0.000]

7.3.9 State asymmetry with respect to measures of potential growth and development

In this paragraph we analyse state asymmetry of monetary transmission with respect to selected measures of potential growth and development. Analogously as in the previous paragraphs, the models, estimation results and corresponding graphs employed here are presented in Table 7.21, Table 7.22, and Figure A9.8 (Appendix A.9) respectively.

As was already mentioned in paragraph 6.5.7, growth of potential GDP (model no. 1) is the only variable which was found to be a relevant transition variable for all three equations constituting the model of the monetary transmission mechanism. We find that high potential growth corresponds with lower effectiveness of the monetary policy with respect to both inflation and the output gap – a pattern which results from a lower response of the interest rate to interest rate shock during periods of high potential growth. At the same time, potential growth has no significant impact on the efficiency of the monetary policy. Since potential growth is a significant transition variable for all three equations, it is difficult to point to the specific theoretical concepts which stand behind these results. Apart from some of the concepts that were presented in subsection 3.4 (structural changes in the U.S. economy), one may expect that the Greenspan standard played an important role in shaping state asymmetry of monetary transmission with respect to potential growth. We argue, however, that the obtained results may signal a positive relation between the natural interest rate and the marginal productivity of capital[76] – in periods of high potential growth the profitability of new investments may be large enough to make investment decisions relatively irresponsive to moderate changes in the level of interest rates as long as the actual interest rate is significantly lower than the natural one.

Although the research and development outlays to the GDP (real) ratio were found to be a statistically significant transition variable for the inflation equation, we find no statistically

[76] We are not particular about any specific notion of the natural interest rate.

significant relation between the ratio and the six measures characterising monetary transmission.

Table 7.21 Final model selection when modelling state-dependency with respect to the selected measures of potential growth and development

No.	s_t	Short data description	inflation equation	output gap equation	interest rate equation
1	gdp_pot_t	Real potential gross domestic product, annualised percent change from quarter ago	$LSTAR1$	$LSTAR1$	$LSTAR1$
2	rd_gdp_t	Real gross domestic product: research and development, percent of real gross domestic product, (real ratio)	$LSTAR1$	$LINEAR$	$LINEAR$

Table 7.22 The results of estimation of equations (7.2) for the selected measures of potential growth and development

No.	s_t	$CSGIRF_t^M(\pi,\Omega_t)$	$CSGIRF_t^M(x,\Omega_t)$	$CSGIRF_t^M(i,\Omega_t)$	$Effectiv(\pi,\Omega_t)$	$Effectiv(x,\Omega_t)$	$Efficien(\Omega_t)$
1	gdp_pot_t	-0.574 [0.000]	4.393 [0.000]	-13.063 [0.000]	-0.091 [0.000]	-2.027 [0.000]	169.899 [0.234]
2	rd_gdp_t	0.000 [0.794]	0.000 [0.978]	0.000 [0.565]	0.000 [0.872]	0.000 [0.597]	0.000 [0.793]

7.3.10 State asymmetry with respect to measures of financial development

Here we deal with state asymmetry of monetary transmission with respect to selected measures of financial development of the economy. Table 7.23, Table 7.24 and Figure A9.9 (Appendix A.9) present the models exploited here, the results of estimation of equations (7.2) and the relevant graphs, respectively.

We find that higher values of MZM stock to GDP (nominal) ratio (model no. 1) result in higher responses of all model variables to interest rate shock and higher effectiveness of the monetary policy with respect to inflation and the output gap. Table 7.23 shows that state asymmetry of monetary transmission is due to state-dependency of the output gap equation. Bearing in mind that the analysed measure may serve as a proxy of development of the banking system and that the banking sector is sensitive to changes in interest rates, the obtained results are quite intuitive – the larger or more developed the banking system, the larger its share in GDP and the more effective the monetary policy is. A negative estimate on the measure of efficiency means that the higher the value of MZM to GDP ratio, the lower the costs of disinflation and the larger the inflation costs of the expansionary monetary policy are.

A very similar pattern to the one described above is shared when the assets of money market mutual funds to the GDP (nominal) ratio is a transition variable (model no. 3). The main important difference is that in such a framework the response of the interest rate to the interest rate shock is smaller for higher values of the ratio, which may reflect a subsidiary role of money market funds in passing through monetary policy shocks into the real economy. Since in that case the interest rate equation is also state-dependent, one may expect that the relative size of money market funds is an important information variable for the monetary authorities.

Table 7.23 Final model selection when modelling state-dependency with respect to the selected measures of financial development of the economy

No.	s_t	Short data description	inflation equation	output gap equation	interest rate equation
		Money supply to GDP ratios			
1	mzm_gdp_t	MZM (money zero maturity) stock to gross domestic product (nominal ratio)	$LINEAR$	$ESTAR$	$LINEAR$
		Other measures			
2	mf_gdp_t	Money market mutual funds: total financial assets, percent of gross domestic product (nominal ratio)	$LINEAR$	$LSTAR1$	$LSTAR1$

Table 7.24 The results of estimation of equations (7.2) for the selected measures of financial development of the economy

No.	s_t	$CSGIRF_t^M(\pi,\Omega_t)$	$CSGIRF_t^M(x,\Omega_t)$	$CSGIRF_t^M(i,\Omega_t)$	$Effectiv(\pi,\Omega_t)$	$Effectiv(x,\Omega_t)$	$Efficien(\Omega_t)$
				Money supply to GDP ratios			
1	mzm_gdp_t	0.230 [0.000]	0.668 [0.000]	0.628 [0.000]	0.141 [0.000]	0.220 [0.000]	-0.944 [0.000]
				Other measures			
2	mf_gdp_t	0.304 [0.000]	0.849 [0.000]	-0.794 [0.000]	0.019 [0.000]	0.121 [0.000]	-0.542 [0.000]

7.3.11 State asymmetry with respect to variables related to some aspects of the Greenspan standard

In this paragraph (the last one in this subsection) we discuss state asymmetry of monetary transmission with respect to selected variables related to some aspects of the Greenspan standard. Table 7.25 presents the models employed here, while Table 7.26 reveals the estimations of equations (7.2). The relevant graphs are available in Appendix A.9 (Figure A9.10).

According to the analysis performed here, monetary transmission reveals significant state asymmetry when the growth rates of the S&P 500© (model no. 1) and Wilshire 5000 Full Cap

Price Index© (model no. 2) are transition variables. Such a result is interesting if we recall that out of the 6 different measures of stock market dynamics, only those two variables yielded significant state asymmetry of monetary transmission. The dynamics of the Dow Jones Industrial Average© was also found to be an important transition variable but it did not result in significant patterns of state asymmetry, while the other three measures of dynamics of the stock market (NASDAQ Composite Index©, Dow Jones Composite©, NASDAQ 100©) were not selected as transition variables, which lead to $STAR$ models being preferred over the linear baseline. Moreover, in each case it is the output gap equation (not the interest rate equation) which is responsible for state asymmetry of monetary transmission. The results obtained here mean that we have discovered no special role for the dynamics of the stock market as a variable influencing the monetary policy rule. In contrast, we have found an important role for the dynamics of the stock market as a factor shaping the output gap equation.

Table 7.25 Final model selection when modelling state-dependency with respect to the selected variables related to some aspects of Greenspan standard

No.	s_t	Short data description	inflation equation	output gap equation	interest rate equation
		Stock prices			
1	$sp500_t$	S&P 500©, annualised percent change from quarter ago	$LINEAR$	$ESTAR$	$LINEAR$
2	$wilsh_t$	Wilshire 5000 Full Cap Price Index©, annualised percent change from quarter ago	$LINEAR$	$LSTAR2$	$LINEAR$
3	$djia_t$	Dow Jones Industrial Average©, annualised percent change from quarter ago	$LINEAR$	$LSTAR2$	$LINEAR$
		Real estate prices			
4	$spcs_t$	S&P/Case-Shiller U.S. National Home Price Index©, annualised percent change from quarter ago	$LINEAR$	$LINEAR$	$LSTAR1$
		Commodity prices			
5	wti_t	Spot oil price: West Texas Intermediate©, dollars per barrel, annualised percent change from quarter ago	$LINEAR$	$LINEAR$	$LSTAR1$

The patterns of state asymmetry of monetary transmission (model nos. 1 and 2) obtained here show that the responses of all model variables as well as the effectiveness of the monetary policy with respect to inflation and the output gap are smaller when the dynamics of the stock market is high. Such relations are easily understandable in the perspective of *credit channel theory* (rather than the Greenspan standard) – high dynamics of the stock market may be related to relatively easy access to capital markets, which become more attractive as an alternative to traditional money and credit markets. Model no. 2 (insignificant estimates for model no. 1) implies that in such a situation the costs of the disinflation policy are relatively high but the inflation costs of the expansionary monetary policy are relatively small.

Surprisingly, although the dynamics of real estate prices and commodity prices were found to be important transition variables for the interest rate equation (consistency with the Greenspan standard), we detected no robust patterns of monetary transmission asymmetry with respect to those variables.

Table 7.26 The results of estimation of equations (7.2) for the selected variables related to some aspects of Greenspan standard

No.	s_t	$CSGIRF_t^M(\pi,\Omega_t)$	$CSGIRF_t^M(x,\Omega_t)$	$CSGIRF_t^M(i,\Omega_t)$	$Effectiv(\pi,\Omega_t)$	$Effectiv(x,\Omega_t)$	$Efficien(\Omega_t)$
				Stock prices			
1	$sp500_t$	-0.029 [0.000]	-0.161 [0.000]	-0.125 [0.000]	-0.010 [0.000]	-0.028 [0.000]	0.281 [0.655]
2	$wilsh_t$	-0.008 [0.000]	-0.045 [0.000]	-0.035 [0.000]	-0.004 [0.000]	-0.011 [0.001]	0.071 [0.000]
3	$djia_t$	0.001 [0.606]	0.008 [0.371]	0.005 [0.490]	0.000 [0.612]	0.002 [0.425]	-0.014 [0.318]
				Real estate prices			
4	$spcs_t$	0.000 [0.678]	0.000 [0.093]	0.000 [0.894]	0.000 [0.698]	0.000 [0.313]	0.000 [0.441]
				Commodity prices			
5	wti_t	0.001 [0.757]	0.000 [0.644]	-0.007 [0.432]	0.000 [0.100]	0.000 [0.090]	0.000 [0.172]

7.3.12 General conclusions from the analysis of state asymmetries

The analysis performed here shows that the adopted framework is successful at identifying statistically significant state asymmetries of monetary transmission. Despite a conservative approach to testing state-dependency and comparing $STAR$ models to linear baselines, variables from all but one of the main groups were found to deliver significant patterns of state asymmetry of monetary transmission (see Table 7.27). Moreover, the obtained patterns of state asymmetries, which were particularly strong in the case of measures of business cycle and climate, uncertainty, and composition of the economy, are explicable in the spirit of the theories and concepts which were described in sections 2 and 3.

Although the analysis is based on historical (pre-crisis) data, we believe that the obtained results might be useful in conducting a better monetary policy. Having knowledge of state asymmetries of monetary transmission may not only help to track structural changes in the propagation of monetary shocks but may also facilitate in optimising the schedule of monetary policy actions (e.g. as to conduct disinflation when the sacrifice ratio is low). Thus the obtained results might be beneficial in both a long- and short-term perspective of the monetary policy. As a warning, the obtained results should be confirmed by other studies whose focus point should be broadly defined robustness of the patterns of state asymmetry (e.g. robustness with respect to the econometric framework, estimation sample, selection of transition variables, etc.). Finally, it is always worth recalling that the usefulness of any empirical results may be seriously limited by the Lucas critique.

Table 7.27 Percentage of cases in which significant patterns of state asymmetry of monetary transmission were found

	inflation	output gap	interest rate	effectiveness inflation	effectiveness output gap	efficiency
business cycle and climate	100%	75%	100%	75%	100%	100%
labour market conditions	50%	50%	50%	50%	50%	25%
financial conditions	28%	39%	39%	33%	33%	28%
- indices of financial conditions	43%	57%	57%	43%	43%	14%
- monetary aggregates	50%	75%	75%	75%	75%	75%
- interest rate quality spreads	0%	0%	0%	0%	0%	0%
- quality of credit portfolio	0%	0%	0%	0%	0%	20%
uncertainty	100%	100%	50%	100%	100%	50%
globalisation	40%	30%	30%	40%	30%	20%
- world data	75%	75%	50%	75%	75%	25%
- U.S. data	17%	0%	17%	17%	0%	17%
composition of the economy	100%	100%	100%	50%	100%	100%
potential growth and development	20%	20%	20%	20%	20%	0%
financial development	14%	14%	14%	14%	14%	14%
- money supply to GDP ratios	50%	50%	50%	50%	50%	50%
- bank assets ratios	0%	0%	0%	0%	0%	0%
- other measures	25%	25%	25%	25%	25%	25%
Greenspan conundrum	0%	0%	0%	0%	0%	0%
Greenspan standard	18%	18%	18%	18%	18%	9%
- stock prices	33%	33%	33%	33%	33%	17%
- real estate prices	0%	0%	0%	0%	0%	0%
- commodity prices	0%	0%	0%	0%	0%	0%
overall	33%	33%	33%	32%	33%	25%

no state asymmetry	0%	(0%, 20%]	(20%, 40%]	(40%, 60%]	(60%, 80%]	(80%, 100%]	state asymmetry

7.4 Summary

In this section we have analysed and discussed various types of asymmetry of monetary transmission. The analysis, which was based on $STAR$ models estimated in section 6 and on generalised impulse response functions, led us to both methodological and empirical findings. Although the adopted framework pointed to the existence of sign and size asymmetries, the obtained patterns of asymmetries were very sensitive to the choice of background model. Therefore, as an idea for further research, we suggested employment of a different framework which should be designed to focus on identification of monetary policy shocks and the impulse propagation mechanism themselves rather than on identification of a model which only later gives rise to (generalised) impulse response functions. In our opinion, the propensity score weighting in the form which was proposed by Angrist, Jordà, and Kuersteiner (2013) seems to be a very interesting alternative to the standard approach which is based on the estimation of the data generating process.

On the contrary, the adopted framework was very successful at identifying state asymmetry of monetary transmission. In a nutshell, the existence of theoretically explicable patterns of state asymmetries were detected with respect to variables from all but one of the groups of proposed variables (see Table 7.28 for a full list). The strongest patterns of state asymmetry were observed in the case of measures of business cycle and climate, uncertainty, and composition of the economy.

Table 7.28 List of variables with respect to which significant patterns of state asymmetry of monetary transmission were found

	business cycle and climate
1	Capacity utilization
2	Chicago Fed National Activity Index: three month moving average
3	Chicago Fed National Activity Index: diffusion index
4	University of Michigan: Consumer Sentiment Index©
	labour market conditions
5	Compensation of employees: wages and salaries, annualised percent change from quarter ago
6	Labour Market Conditions Index
	financial conditions
7	CredAbility Consumer Distress Index
8	Chicago Fed National Financial Conditions Leverage Subindex
9	Chicago Fed National Financial Conditions Credit Subindex
10	Chicago Fed National Financial Conditions Risk Subindex
11	Board of governors monetary base, annualised percent change from quarter ago
12	MZM (money zero maturity) stock, annualised percent change from quarter ago
13	M2 money stock, annualised percent change from quarter ago
14	Nonperforming loans to total loans for all U.S. banks
15	Delinquency rate on all loans
	uncertainty
16	Economic Policy Uncertainty Index for United States by Baker, Bloom and Davis (2013)
17	Equity Market-related Economic Uncertainty Index by Baker, Bloom and Davis (2013)
	globalisation
18	World gross domestic product, constant 2005 dollar, annualised percent change from quarter ago
19	World gross savings, percent of world gross domestic product (nominal ratio)
20	World exports of goods and services, percent of world gross domestic product, (nominal ratio)
21	Real exports of goods and services, percent of real gross domestic product (real ratio)
22	Balance on current account, percent of gross domestic product (nominal ratio)
	composition of the economy
23	Labour share in nonfarm business sector
24	Services: value added: percent of gross domestic product (nominal ratio)
	potential growth and development
25	Real potential gross domestic product, annualised percent change from quarter ago
26	Real gross domestic product: research and development, percent of real gross domestic product, (real ratio)

	financial development of the economy
27	MZM (money zero maturity) stock to gross domestic product (nominal ratio)
28	Money market mutual funds: total financial assets, percent of gross domestic product (nominal ratio)
	Greenspan standard
29	S&P 500©, annualised percent change from quarter ago
30	Wilshire 5000 Full Cap Price Index©, annualised percent change from quarter ago
31	Dow Jones Industrial Average©, annualised percent change from quarter ago
32	S&P/Case-Shiller U.S. National Home Price Index©, annualised percent change from quarter ago
33	Spot oil price: West Texas Intermediate©, dollars per barrel, annualised percent change from quarter ago

We argue that the results are potentially very useful from the perspective of conducting a successful monetary policy. They may be particularly helpful in optimising the schedule of interest rate hikes and cuts as to minimise sacrifice ratio or maximise gain ratio, respectively. Moreover the detected patterns of state asymmetry suggest non-negligible structural changes in the monetary transmission mechanism which could be taken into account by the central bankers, e.g. in order to adjust their projection models. As we emphasised, our findings are not specific to extremely turbulent periods when departure from the standard paradigm would not be surprising, but refer to the economic commonness. Then one may expect that gains from incorporating state asymmetries in the decision process of conducting monetary policy are even larger if e.g. the recent Great Recession is also concerned. Inherently, the Lucas critique should always be treated as an admonition against abusing the empirical results.

8. Conclusions

The thesis dealt with the problems of nonlinearity and state-dependency of the monetary transmission model and asymmetric impulse responses in the Greenspan era. At the very beginning (section 1) we precisely defined all of the concepts and explained why we find the issue of nonlinearity and state-dependency of monetary transmission as being of utmost importance. In particular, we focused on the central bankers' perspective to show that the results are potentially very useful in the context of conducting a successful monetary policy and in solving some strategic dilemmas regarding scheduling monetary policy actions. Moreover, we justified the selection of the Greenspan era as our estimation sample on both economic and econometric grounds.

In the following section (section 2) we presented the general premises behind nonlinearity and state-dependency of the monetary transmission mechanism. Both the theoretical and empirical aspects were discussed not only at the level of every single equation constituting the monetary transmission mechanism (i.e. the Phillips curve, the IS curve and the Taylor rule), but also from the perspective of the monetary transmission mechanism as an econometric system which is potent to generate impulse response functions. The analysed literature provided strong evidence that the monetary transmission mechanism exhibits significant nonlinearity and state-dependency at individual equation levels, and asymmetries in impulse responses at the system level.

Bearing in mind that the Greenspan era was quite a specific period in the economic history of the U.S., in section 3 we explored the literature so as to find the premises behind the nonlinearity and state-dependency of the monetary transmission mechanism which were specific to the Greenspan era. Interestingly, we investigated the phenomenon of the Great Moderation so as to organise our considerations and we found that globalisation, structural changes in the U.S. economy, crises and market distresses and the Greenspan standard were potentially important (and possibly endemic to the Greenspan era) sources of nonlinearities and state-dependency of the monetary transmission mechanism.

After the literature overview, we turned to the empirical part of the thesis. In section 4 we introduced and estimated the baseline model of the monetary transmission mechanism. The diagnostic tests and impulse response analysis performed here proved that the model has desirable properties from both an econometric and economic perspective and could serve as a reference model for later modelling of nonlinearities and state-dependency of the monetary transmission mechanism.

In section 5 we demonstrated that the baseline model of the monetary transmission mechanism hides some peculiarities which are not usually detected when a typical procedure of econometric modelling is applied. Specifically, the proposed tests broadly rejected the null hypotheses of linearity and state-independency of the baseline model of the monetary transmission mechanism despite a conservative approach to testing. From a practical point of view such a finding means that there is still room for improvement in how the empirical regularities are exploited in the process of conducting the monetary policy. What is important such a quality is not specific to extremely turbulent periods like the Great Depression or the Great Recession but characterises an environment in which monetary decisions are made on a regular basis.

The above-mentioned results justify why section 6 was devoted to econometric modelling of nonlinearity and state-dependency of the monetary transmission mechanism. In accordance with the $STAR$ modelling framework, the concept and details of which were also presented, we specified, estimated and evaluated a battery of nonlinear or state-dependent ($STAR$) models of the monetary transmission mechanism. Each of these was then compared with the linear baseline, and only more parsimonious $STAR$ models were selected for the stage of calculating generalised impulse response functions.

Finally, in section 7 we analysed generalised impulse response functions in the context of asymmetry of monetary transmission, which allowed us to come to the final conclusions of the thesis.

On the one hand, the adopted framework points at the existence of statistically significant sign and size asymmetries, but on the other hand the obtained patterns of sign and size asymmetries were not robust among the estimated models. Therefore, in that respect the general conclusion is rather methodological than empirical – we believe that a trustworthy analysis of sign and size asymmetries requires a framework which very precisely identifies monetary policy shocks and explicitly controls the existence and patterns of sign and size asymmetries in the impulse propagation mechanism. In other words, sign and size asymmetries should be directly identifiable at the stage of estimation rather than identifiable only afterwards as a mathematical consequence of the functional form of the monetary transmission model combined with the empirical data. An example idea would be to estimate monetary policy shocks at the first stage of estimation and to plug them into the second stage of estimation where they may also serve as, e.g. a transition variable in the $STAR$ modelling framework. The problem to solve, however, is how to consistently estimate such a two-stage regression in the presence of the specific nonlinear simultaneity problem, i.e. identification of monetary policy shocks and the nonlinear impulse propagation mechanism at the same time. Alternatively, a semiparametric approach based on propensity score weighting instead of estimation of the macroeconometric model (Angrist, Jordà, and Kuersteiner 2013) seems to be an inspiring idea as how to avoid the abovementioned problems by changing the paradigm of empirical modelling the monetary transmission mechanism.

As far as the analysis of state asymmetries is concerned, we believe that the adopted framework did very well in identifying the sources of state-dependency of the estimated equations and state asymmetry of monetary transmission. The variables from all but one main group were found to deliver significant patterns of state asymmetry and, what is also important, the obtained patterns of state asymmetries were explicable in the spirit of the theories and concepts which were described in sections 2 and 3. In our opinion, knowledge of state asymmetries of monetary transmission may not only help to track structural changes in the propagation of monetary shocks but may also facilitate in optimisation of the schedule of monetary policy moves. Thus the obtained results might be beneficial in both a long- and short-term perspective of the monetary policy, although the Lucas critique should always be taken into consideration.

As a warning, all of the results obtained in this thesis should be treated with a natural dose of caution. Since the scope is quite general and we dealt with many sources of asymmetry of monetary transmission, it would be desirable to conduct research focused on selected issues (e.g. labour market conditions or globalisation). Then the variety of possible robustness checks and nuances that could be investigated and discussed would be larger. The author of this thesis plans to explore such a research agenda in subsequent studies.

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List of acronyms and abbreviations

AIC	Akaike information criterion
AR	autoregressive
ARCH	autoregressive conditional heteroscedasticity
BIC	Bayesian information criterion
CFNFC	Chicago Fed National Financial Conditions
CSGIRF	cumulative standardised generalised impulse response function
DSGE	dynamic stochastic general equilibrium
ESTAR	exponential smooth transition autoregressive
Fed	Federal Reserve System
FMCG	fast-moving consumer goods
FOMC	Federal Open Market Committee
GDP	gross domestic product
GIRF	generalised impulse response function
GMM	generalized method of moments
GNP	gross national product
HNKPC	hybrid New Keynesian Phillips curve
HP filter	Hodrick-Prescott filter
ICT	information and communications technology
IRF	impulse response function
IS curve	investment-saving curve
LM curve	liquidity preferences – money supply curve
LM test	Lagrange multiplier test
LR test	likelihood ratio test
LSTAR	logistic smooth transition autoregressive
LSTAR1	logistic smooth transition autoregressive with one threshold
LSTAR2	logistic smooth transition autoregressive with two thresholds
LTCM	Long-Term Capital Management
MLE	maximum likelihood estimation
MZM	money zero maturity
NASDAQ	National Association of Securities Dealers Automated Quotations
NFA	net foreign assets
NKPC	New Keynesian Phillips curve
NLS	nonlinear least squares

OPG	outer product of gradient
QMLE	quasi maximum likelihood estimation
R&D	research and development
RBC	real business cycle
RESET	regression equation specification error test
S&P	Standard and Poor's
SGIRF	standardised generalised impulse response function
SIC	Schwarz information criterion
SIRF	standardised impulse response function
SM	sample mean
SV	sample variance
SSR	sum of squared residuals
STAR	smooth transition autoregressive
U.S.	United States of America
VAR	vector autoregressive
VECM	vector error correction model

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Appendix A.1

Table A1.1 Overview of micro-based concepts behind nonlinearity and state-dependency of the Phillips curve

	Concept / model	References	Implications for the shape of the Phillips curve
(1)	*capacity constraint*	Clark et al. (2001); Dupasquier and Ricketts (1998); Hansen and Prescott (2005); Mackleem (1997)	convex
(2)	*misperception or signal extraction*	Dupasquier and Ricketts (1998); Lucas (1972, 1973); Maćkowiak and Wiederholt (2009, 2011)	the slope depends positively on the variance of inflation
(3)	*costly adjustments*	Ball and Mankiw (1994); Ball et al. (1988); Burstein (2006); Dupasquier and Ricketts (1998)	the slope depends positively on the level of inflation; possibly convex
(4a)	*downward nominal wage rigidity*	Akerlof et al. (1996); Dupasquier and Ricketts (1998); Lindbeck and Snower (1986, 1988); Shafir et al. (1997); Snowdon and Vane (2005, Ch. 7.7.2); Stiglitz (1984b)	the slope depends positively on the output gap or inflation expectations; possibly convex
(4b)	*downward real wage rigidity*	Lindbeck and Snower (1986, 1988); Snowdon and Vane (2005, Ch. 7.7.2); Stiglitz (1984b)	steeper upward than downward; the difference between the two might be a decreasing function of the inflation level
(5a)	*monopolistic competition*	Dupasquier and Ricketts (1998)	concave
(5b)	*limit pricing as an entry deterrent*	Stiglitz (1984a)	concave
(5c)	*collusive behaviour*	Stiglitz (1984a)	steeper upward than downward; the difference between the two might be a decreasing function of the inflation level
(5d)	*procyclical competitiveness*	Rotemberg and Woodford (1991)	steeper during expansions than during recessions; possibly convex
(6)	*imperfect credibility*	Alichi et al. (2009), Isard et al. (2001)	the slope depends negatively on the central bank's credibility; possibly convex upward and concave downward
(7a)	*customer markets*	Snowdon and Vane (2005, Ch. 7.7.1)	concave
(7b)	*costly search*	Stiglitz (1984a)	possibly convex
(7c)	*judging quality by price*	Allen (1988); Stiglitz (1984a, 1987)	convex
(7d)	*pricing points*	Kashyap (1995); Snir et al. (2012)	steeper downward than upward and possibly concave for low levels of inflation
(7e)	*asymmetric price adjustment in the small*	Chen et al. (2008)	steeper upward than downward and possibly convex for low levels of inflation
(7f)	*customers' anger*	Rotemberg (2002)	concave; possibly state-dependent with respect to some macroeconomic variables
(7g)	*implicit contracts*	Kahneman et al. (1986); Okun, (1981)	steeper downward than upward when inflation is stable at a low level
(7h)	*procyclical elasticity of demand*	Bils (1989); Blinder (1994)	steeper during expansions than during recessions; possibly convexi

(8)	*macroeconomic externalities* and *coordination failures*	Akerlof and Yellen (1985a, 1985b); Ball and Romer (1991); Blanchard and Kiyotaki (1987); Cooper and John (1988); Diamond (1982); Kaplan and Menzio (2013); Romer (2012, Ch. 6.8) Rotemberg (1987); Shleifer and Vishny (1988); Snowdon and Vane (2005, Ch. 7.7); Summers (1988)	state- and 'sunspot-dependent' with respect to variables which influence the agents' expectations; possible non-existence of the Phillips curve

Table A1.2 Overview of studies on nonlinearity and state-dependency of the Phillips curve for the U.S. economy

	Period	**Econometric method**	**Measure of the output gap**	**Measure of inflation expectations**	**Conclusions**
Clark, Laxton and Rose (1995)	1964q1-1990q4	Kinked piecewise linear function (one kink)	two-sided moving average, Harvey and Jaeger (1993) model, HP filter, quadratic time trend	Michigan Survey	significant nonlinearity towards convexity
Clements and Sensier (2003)	1960q2-2001q1	Threshold piecewise linear function (one threshold)	HP filter	lagged inflation	significant nonlinearity towards convexity for CPI inflation, no significant nonlinearity for GDP deflator
Filardo (1998)	1959q2-1997q3	Kinked piecewise linear function (two kinks)	HP filter	auxiliary regression on Michigan Survey expectations	significant nonlinearity towards both convexity and concavity for positive and negative output gap, respectively
Saglio and López-Villavicencio (2012)	1985q1-2011q4	Kinked piecewise linear function (one kink), smooth transition regression (one threshold) and combination of both	HP filter	lagged inflation	significant nonlinearity towards concavity; state-dependency with respect to trend inflation and its volatility (flatness for low and stable inflation) and capacity utilisation (steepness for high level of capacity utilisation)
Turner (1995)	1962-1993	Kinked piecewise linear function (one kink)	HP filter	lagged inflation	significant nonlinearity towards convexity
Yates (1998)	1800-1938	Kinked piecewise linear function (one two-dimensional kink)	HP filter	lagged inflation	no significant nonlinearity nor state-dependency with respect to the sign of inflation (inflation vs deflation) and its first difference (raising inflation vs disinflation)

Table A1.3 Overview of studies on nonlinearity and state-dependency of the IS curve for the U.S. economy

	Period	**Econometric method**	**Endogenous variable(s)**	**Explanatory variables**	**Conclusions**
Cover (1992)	1951q1-1987q4	Linear regressions with separate variables for positive and negative monetary policy shocks	quarterly growth rate of gross national product	lagged endogenous variable, the first difference of the rate on 90-day treasury bills, positive and negative monetary policy shocks derived from auxiliary regression of money supply (M1)	stronger effects of restrictive than expansionary monetary policy shocks (insignificant effect in the latter case)
DeLong and Summers (1988)	1889-1929, 1947-1987	Linear regressions with an additional variable for negative monetary policy shocks	annual average gross national product	lagged endogenous variable, time trend, monetary policy shocks derived from auxiliary regression of money supply (M2), additional variable for negative monetary policy shocks	stronger effects of restrictive than expansionary monetary policy shocks (insignificant effect in the latter case)
Garcia and Shaller (2002)	1955q2-1993q1	Markov switching model	quarterly growth rate of industrial production	baseline: lagged endogenous variable, federal funds rate; robustness checks: VAR-based monetary policy shocks instead of federal funds rate	stronger effects of monetary policy in a recession than in an expansion
Kakes (1998)	1971q1-1999q4	Markov switching model	annual growth rate of industrial production	baseline: lagged endogenous variable, federal funds rate; robustness checks: VAR-based monetary policy shocks instead of federal funds rate	stronger effects of the monetary policy in a recession than in an expansion
Karras and Stokes (1999)	1960q4-1993q4	Nonlinear regressions with separate variables for positive and negative monetary policy shocks and endogenised breakpoint of asymmetry	quarterly growth rates of: gross domestic product, private consumption, fixed investments	lagged endogenous variable, change in the three-month Treasury bill rate, positive and negative monetary policy shocks derived from auxiliary regression of money supply (M1)	stronger effects of restrictive than expansionary monetary policy shocks (insignificant effect in the latter case) for output and fixed investments (no such evidence for private consumption)
Lo and Piger (2005)	1955q3-2002q4	Unobserved-components model with regime switching	logarithm of industrial production	equation of transitory component: interest rate-based monetary policy shocks derived from an identified VAR; state dummy variables: sign and size of a monetary shock, and phase of business cycle (recession periods identified by *NBER*)	stronger effects of the monetary policy in a recession than in an expansion, 'much less evidence for any asymmetry related to the direction or size of the policy action'
Morgan (1993)	1963q2-1992q1 and excluding 1979q4-1982q4	Linear regressions with separate variables for positive and negative monetary policy shocks	quarterly growth rate of gross domestic product (supposition – no explicit information)	two regressions: (1) interest rate and (2) Boshen-Mills-based monetary policy shocks derived from auxiliary regressions	stronger effects of restrictive than expansionary monetary policy shocks (usually insignificant effect in the latter case)

Ravn and Sola (2004)	1948q1-1987q4	Linear regression with separate variables for positive, negative, big and small monetary policy shocks	quarterly growth rate of gross national product	lagged endogenous variable, changes in the T-bill rate; positive, negative, big and small monetary policy shocks derived from auxiliary Markov switching regression of money supply (M1)	no difference between various types of monetary policy shocks
Ravn and Sola (2004)	1960q1-1995q4	Linear regression with separate variables for positive, negative, big and small monetary policy shocks	quarterly growth rate of gross national product	lagged endogenous variable, changes in the T-bill rate; positive, negative, big and small monetary policy shocks derived from auxiliary Markov switching regression of federal funds rate	neutrality of all but small negative monetary policy shocks
Senda (2001)	1873-1913, 1954-1994	Linear regression with separate variables for positive, negative, big and small monetary policy shocks	logarithm of gross domestic product	lagged endogenous variable, time trend, positive, negative, big and small monetary policy shocks derived from auxiliary regressions of money stock (two versions)	no difference between positive and negative monetary policy shocks
Sim (2009)	1970m1-2009m1	Quantile regression	growth rate of the industrial production index	lagged endogenous variable, change in the three-month Treasury yield, monetary policy shocks derived from auxiliary regressions of money supply (M1 and M2)	stronger effects of restrictive than expansionary monetary policy shocks; stronger effects of monetary policy shocks when the output growth is in its tails (recession or expansion), especially in the right tail (expansion)

Table A1.4 Overview of studies on nonlinearity and state-dependency of the Taylor rule for the U.S. economy

	Period	Econometric method	Explanatory variables	Additional remarks	Conclusions
Assenmacher-Wesche (2006)	1973q1-2004q4	Markov switching model	lagged federal funds rate, annualised quarterly changes in the log of the gross domestic product deflator, percentage deviation of gross domestic product from its trend value calculated with the Hodrick-Prescott filter	'error term is allowed to switch between a high variance and a low variance state' independently of coefficient regimes, no forward-looking expectations in the model	stronger interest-rate smoothing and reaction to the output gap but smaller to inflation in a high-inflation regime than in a low-inflation regime
Bec, Salem and Collard (2002)	1982m10-1998m8	Threshold model	lagged federal funds rate, annual rate of change of the consumer price index, log differences between the industrial production index and its Hodrick-Prescott filtered trend	threshold variable: output gap	stronger reaction to inflationary than deflationary pressures
Castro (2011)	1982m10-2007m12	Logistic Smooth Transition Regression	lagged federal funds rate, annual rate of change of the consumer price index, log differences between the industrial production index and its Hodrick-Prescott filtered trend	transition variables: inflation rate; both forward- and backward-looking versions estimated	no evidence of nonlinearity if the forward-looking version of the Taylor rule with interest-rate smoothing is estimated
Cukierman and Muscatelli (2008)	1960q1-2005q4	Hyperbolic Tangent Smooth Transition Regression	lagged federal funds rate, annualised rate of quarterly change of the consumer price index, percentage deviation of gross domestic product from the trend estimated by the Congressional Budget Office	transition variables: inflation gap for coefficient on inflation, output gap for coefficient on output gap, no forward-looking expectations in the model but estimation via generalised method of moments	reaction function under: Martin – convex with respect to inflation and output gaps, Burns/Miller – concave with respect to output gap; Volcker – no evidence of nonlinearities; Greenspan – concave with respect to output gap;
Dolado, Maria-Dolores and Naveira (2005)	1984m1-2011m9	Linear regression with an additional term $x_t \pi_t$	lagged federal funds rate, quarterly rate of change of the consumer price index, log differences between industrial production index and its Hodrick-Prescott filtered trend	no forward-looking expectations in the model but estimation via generalised method of moments	no evidence of nonlinearities
Dolado, Maria-Dolores and Ruge-Murcia (2004)	1970m1-1979m6, 1983m1-2002m12; 1960q1-1979q2, 1970q1-2002q4	Linear regression with an additional term $s_{\pi_t}^2$ (conditional variance of inflation)	lagged federal funds rate, conditional variance of inflation estimated from the aggregate supply relation ($s_{\pi_t}^2$); monthly: annual percentage change in the consumer price index, log differences between industrial production index and its Hodrick-Prescott filtered trend; quarterly: annualised quarterly percentage change in the implicit gross domestic product deflator	both forward- and backward-looking versions estimated	no evidence of nonlinearities before 1979 (pre-Volcker era); after 1983 (Volcker-Greenspan era) 'positive deviations of inflation from its target appear to be weighted more severely than negative ones, even if they are of the same magnitude'
Florio (2006)	1979q3-2004q3	Hyperbolic Tangent Smooth Transition	lagged federal funds rate, annualised quarterly changes in the log of the gross domestic product deflator, percentage deviation of gross domestic	transition variable: first difference of federal funds rate; no forward-looking expectations in the model	Volcker-Greenspan era – stronger reaction to an increase than to a decrease in inflation, more interest-rate

		Regression	product from the trend estimated by the Congressional Budget Office	but estimation via generalised method of moments	smoothing in periods of restrictive monetary policy; more cautious behaviour in lowering and rising interest rates in the Volcker and Greenspan eras, respectively
Hayat and Mishra (2010)	1949q1-2008q2, 1965q4-2008q2	Semi-parametric Generalised Additive Model	lagged federal funds rate, annualised quarterly changes in the log of the gross domestic product deflator, percentage deviation of gross domestic product from the trend estimated by the Congressional Budget Office	both forward- and backward-looking versions estimated	monetary authorities tend to react only when inflation or inflation expectations are in a particular range
Kim and Nelson (2006)	1960q1-2001q2	Two-step regression model with time-varying coefficients	lagged federal funds rate, percentage of the gross domestic product deflator, percentage deviation of gross domestic product from the trend estimated by the Congressional Budget Office, standardised prediction errors for inflation and output gap	prediction errors serve as correction biases for changing degree of uncertainty	the sample could be divided into three periods: 1970s (stabilisation of economic activity), 1980s (stabilisation of inflation), 1990s (stabilisation of economic activity)
Kim, Osborn and Sensier (2005)	1960q1-2000q4 (efficiently: 1970q1-2000q4)	Hamilton (2001) nonlinear regression model	lagged federal funds rate, annualised quarterly changes in the log of the gross domestic product deflator, percentage deviation of gross domestic product from the trend estimated by the Congressional Budget Office or with the Hodrick-Prescott filter	forward-looking expectations based on constructed inflation and output gap forecasted values, for inflation forecasts robustness check based on Survey of Professional Forecasters, backward-looking version estimated as a robustness check	significant nonlinearity before 1979 (pre-Volcker era); weak evidence of nonlinearity after 1979 (Volcker-Greenspan era)
Koo, Paya and Peel (2010)	1960q1-1979q2; 1982q4-2008q4	Non-parametric regression and Hyperbolic Tangent Smooth Transition Regression	lagged federal funds rate, annualised quarterly changes in the log of the gross domestic product deflator, percentage deviation of gross domestic product from the trend estimated by the Congressional Budget Office	forward-looking expectations based on constructed inflation and output gap forecasted values	significant nonlinearity before 1979 (pre-Volcker era) – relatively stronger reaction to inflations when it is high, stronger reaction to a recession than to an expansion; weak evidence of nonlinearity after 1982 (Volcker-Greenspan era)
Lee and Son (2013)	1979q1-2008q2	Nonlinear regression with coefficients being polynomial functions of other variables (‘series method’) and structural breaks	lagged federal funds rate, annualised quarterly changes in the log of the gross domestic product deflator, percentage deviation of gross domestic product from the trend estimated by the Congressional Budget Office or with the Hodrick-Prescott filter, two-year growth rate of the S&P 500 price earnings ratio	potential candidates for explanatory variables in coefficient functions: level value of inflation, deviation of inflation from its target level, level value of the interest rate, and various combinations of these candidates	structural breaks in the estimated Taylor rule around 1991 and probably around 1982 and 1987; nonlinearity in the inflation coefficient – stronger reaction to inflationary than deflationary pressures
Pardo, Rautureau and Vallée (2011)	1960q1-2008q4	Markov switching model	lagged federal funds rate, percentage of the gross domestic product deflator, percentage deviation of	federal funds rate measured as four-quarter average	stronger reaction to economic activity and weaker to inflation in periods of

			gross domestic product from the trend estimated by the Congressional Budget Office		high than low volatility
Petersen (2007)	1960q1-2005q4	Logistic Smooth Transition Regression	3-month average growth rate of core personal consumption expenditure index or core consumer price index, percentage deviation of gross domestic product from the trend estimated with the Hodrick-Prescott filter	transition variable: inflation; no smoothing of interest rates (no lagged federal funds rate among explanatory variables)	no evidence of nonlinearity for the 1960-1979 period, significant nonlinearities for the 1985-2005 period – stronger reaction to inflation and output gap when inflation reaches a certain threshold
Surico (2007)	1960q1-2003q2	Linex function reparameterised as a linear regression with additional terms π_t^2 and x_t^2	lagged federal funds rate, changes in the log of: the personal consumption deflator or the gross domestic product deflator (π_t), percentage deviation of gross domestic product from the trend estimated by the Congressional Budget Office (x_t), terms π_t^2 and x_t^2	no forward-looking expectations in the model but estimation via generalised method of moments	reaction function in pre-Volcker concave with respect to output gap; no nonlinearities for the Volcker-Greenspan era
Tillmann (2011)	1982q3-2006q4	Linear regression with an additional term $x_t\pi_t^2$	lagged federal funds rate, annualised rate of change of the personal consumption expenditure deflator (π_t), percentage deviation of real gross domestic product from the trend estimated by the Congressional Budget Office (x_t), term $x_t\pi_t^2$	no forward-looking expectations in the model but estimation via generalised method of moments	the coefficient on term $x_t\pi_t^2$ is significant and positive, but the coefficient on the output gap is no longer significant

Table A1.5 Overview of studies on asymmetries in the monetary transmission mechanism for the U.S. economy

	Period	**Econometric method**	**Endogenous variables**	**Additional remarks**	**Conclusions**
Angrist, Jordà, and Kuersteiner (2013)	1989m7-2005m7, 1989m7-2008m12	Nonparametric estimator based on propensity score weighting	federal funds rate, T-bill rates (3-month, 2- and 10-year), federal funds futures, unemployment rate, monthly growth rate of: industrial production, consumer price index	the econometric method is based on propensity score weighting (not on the estimated model of the monetary transmission mechanism)	stronger effects of restrictive than expansionary monetary policy shocks on industrial production, unemployment and inflation
Alessandrini (2003)	1959m1-2000m12	Threshold VAR	industrial production, consumer prices inflation, commodity prices inflation, federal funds rate, percentage ratio of non-borrowed reserves to total reserves, percentage ratio of total reserves to total reserves in the previous period, credit spread between bonds with Baa rating and bonds with Aaa rating, spread between 3-month prime rate and 3-month T-Bills	threshold variables: annual change in industrial production, annual changes in the S&P 500, annual changes in cash-flows (NIPA), annual changes in dividends (NIPA), Boschen-Mills index	monetary tightening more severe when financial situation is already stretched, especially if cash-flows and dividends are used as proxies of the financial constraint of the economy (consistency with the existence of a credit channel of the monetary policy)
Balke (2002)	1960q1-1997q3, 1960q1-1991q4,	Threshold VAR	quarterly growth rate of gross domestic product, gross domestic product deflator inflation, federal funds rate, threshold variable (three models)	threshold variables: commercial paper (four-to-six month)/T-Bill (six-month) spread, mix of bank loans and commercial paper in total firm external finance, difference between growth rates in the short-term debt of small and large manufacturing firms	stronger effects of monetary policy shocks when credit conditions are ‘tight’, stronger effects of restrictive than expansionary monetary policy shocks
Chang and Jansen (2005)	1976q1-1999q3	Logistic Smooth Transition VECM	real: big-bank loans, small-bank loans, gross domestic product, federal funds rate	Transition variables: change in federal funds rate, change in federal gross domestic product	significant but very temporary asymmetries for large negative monetary shocks, no evidence supporting asymmetries due to bank lending channel
Hoppner, Melzer and Neumann (2005)	1962q1-2002q2	Time-Varying Coefficient VAR	gross domestic product, consumer price index, federal funds rate	recession periods identified by *NBER*	responsiveness of the economy (especially economic activity) to monetary policy shocks steadily decreasing in time, stronger effects of monetary policy when the economy is in a recession
Mandler (2010)	1965q3-2007q2	Threshold VAR	quarterly growth rates of: gross domestic product, gross domestic product deflator, M1 money supply, indicator of commodity prices (oil, agricultural commodities, metals); federal funds rate	threshold variable: inflation	‘qualitative differences (asymmetries) in generalised impulse responses depending on the economy being initially in the high or low inflation regime’; negligible asymmetry due to size of the shocks; stronger reaction of output growth to federal funds rate shock and inflation shock in the high inflation

					regime; stronger reaction of inflation and federal funds rate to federal funds rate and output growth shocks in the low inflation regime
Weise (1999)	1960q2-1995q2	Logistic Smooth Transition VAR	quarterly growth rates of: industrial production index, consumer price index, and M1 money supply	transition variables: lagged endogenous variables, change in consumer price index inflation	stronger but negative effects of monetary policy shock on output and stronger on price level when output growth is high and inflation is rising, larger monetary policy shocks tend to have larger unit impact than smaller ones, at best mild evidence of asymmetry with respect to the sign of monetary policy shocks for large shocks
Zheng (2013)	1973q1-2008q4	Threshold VAR	log deviations from deterministic trend: gross domestic product, commodity price index, real trade weighted US dollar index against major currencies; consumer price index inflation, federal funds rate, adjusted national financial conditions index	threshold variable: adjusted national financial conditions index	stronger effects of monetary policy shocks and worsening of output-inflation trade-off when financial stress is high, larger monetary policy shocks have larger unit impact than smaller ones

Table A1.6 Number of results of searching keywords on google.scholar.com

‘IS curve’	18 000
‘Phillips curve’	38 400
‘Aggregate demand curve’	4 600
‘Aggregate supply curve’	5 200
‘Effects’ and ‘output’ and ‘monetary’ and ‘policy’	1 180 00
‘Effects’ and ‘inflation’ and ‘monetary’ and ‘policy’	682 000
‘Effects’ and ‘output’ and ‘monetary’ and ‘policy’	1 260 00
‘Effects’ and ‘inflation’ and ‘monetary’ and ‘policy’	706 000
‘Effects’ and ‘output’ and ‘monetary’ and ‘interest’ and ‘rates’	2 670 000
‘Effects’ and ‘inflation’ and ‘monetary’ and ‘interest’ and ‘rates’	1 090 000

Source: google.scholar.com [04.07.2014]

Appendix A.2

Table A2.1 Overview of channels through which structural changes in the U.S. economy may influence the shape of the Phillips curve

	Channel	References	Implications for the shape of the Phillips curve
(1)	lower menu and managerial costs related to price changes	Willis (2003)	steepening
(2)	easier comparing prices	Willis (2003)	steepening
(3)	production more responsive to changes in product demand and reduced level of inventories	Cecchetti (2006)	flattening
(4)	increased share of temporary workers	Cecchetti (2006); Willis (2003)	flattening
(5)	increased returns to scale and network effects	Berk (2002)	changing the curvature into a more concave shape
(6)	changes in signal extraction problem	Berk (2002); Campbell (2007)	ambiguous net effect – steepening or flattening
(7)	changes in the formulation of inflation expectations	by analogy with: Berk (2002); Campbell (2007)	possible state-dependency (balance between the backward- and forward-looking components of inflation expectations) with respect to the development of information technology
(8)	composition effect	Alcala and Sancho (2004), Moro (2012); Nakamura and Steinsson (2008)	flattening

Table A2.2 Overview of channels through which structural changes in the U.S. economy may influence the shape of the IS curve

	Channel	References	Implications for the shape of the IS curve
(1)	erosion of a central bank's monopoly position as a supplier of means of payment	Berk (2002); Cecchetti (2006); Woodford (2000)	possible flattening and/or more lagged impact of the short-term interest rate
(2)	dampening the credit channel of the monetary policy	Berk (2002), Cecchetti (2006); Willis (2003)	weakening of the inverse relation between the slope of the IS curve and credit conditions in the economy
(3)	development of hedging instruments and broader access to financing	Berk (2002)	ambiguous net effect – steepening or flattening; more forward-looking characteristic
(4)	better access to information and forecasts	by analogy with: Berk (2002); Campbell (2007)	possible state-dependency (balance between the backward- and forward-looking components of inflation expectations) with respect to the development of information technology
(5)	influencing the income effect of the monetary policy	Berk (2002); Jerman and Quadrini (2006); Vrolijk (1997)	ambiguous net effect – steepening or flattening; we find the steepening effect to be more probable
(6)	influencing the wealth effects of the monetary policy	Berk (2002); Grydaki and Bezemer (2013); Temple (2002)	ambiguous net effect – steepening or flattening; we find the steepening effect to be more probable
(7)	composition effect	Alcala and Sancho (2004); Moro (2012)	steepening

Appendix A.3

Plugging (4.2) into (4.1) yields:

$$\pi_t = [\alpha_0 + (1-\alpha_1)\beta_0] + [\alpha_1 + (1-\alpha_1)\beta_1]\pi_{t-1} + \alpha_2 x_t + (1-\alpha_1)\beta_2 x_{t-1} + $$
$$+(1-\alpha_1)\beta_3 i_{t-1} + \varepsilon_{\pi,t} \qquad \text{(A3.1)}$$

The equation (A3.1) is equivalent to equation (4.7) under the assumption that:

$$\phi_{11} = [\alpha_0 + (1-\alpha_1)\beta_0]$$
$$\phi_{12} = [\alpha_1 + (1-\alpha_1)\beta_1]$$
$$\phi_{13} = \alpha_2$$
$$\phi_{14} = (1-\alpha_1)\beta_2$$
$$\phi_{15} = (1-\alpha_1)\beta_3$$
$$\varepsilon_{\pi,t} = \phi_{16}\epsilon_{\pi,t-1} + \nu_{\pi,t}$$

Similarly, plugging (4.4) and (4.5) into (4.3) yields:

$$x_t = [\gamma_0 + (1-\gamma_1)\delta_0 - \gamma_2\zeta_0] + [(1-\gamma_1)\delta_1 - \gamma_2\zeta_1]\pi_{t-1} +$$
$$+[\gamma_1 + (1-\gamma_1)\delta_2 - \gamma_2\zeta_2]x_{t-1} + [(1-\gamma_1)\delta_3 + \gamma_2 - \gamma_2\zeta_3]i_{t-1} + \varepsilon_{x,t}$$

Analogously:

$$\phi_{21} = [\gamma_0 + (1-\gamma_1)\delta_0 - \gamma_2\zeta_0]$$
$$\phi_{22} = [(1-\gamma_1)\delta_1 - \gamma_2\zeta_1]$$
$$\phi_{23} = [\gamma_1 + (1-\gamma_1)\delta_2 - \gamma_2\zeta_2]$$
$$\phi_{24} = [(1-\gamma_1)\delta_3 + \gamma_2 - \gamma_2\zeta_3]$$
$$\varepsilon_{x,t} = \phi_{25}\epsilon_{x,t-1} + \nu_{x,t}$$

In the case of equations (4.6) and (4.8), mapping is more direct:

$$\phi_{31} = \theta_0$$
$$\phi_{32} = \theta_2$$
$$\phi_{33} = \theta_3$$
$$\phi_{34} = \theta_1$$
$$\varepsilon_{i,t} = \phi_{35}\epsilon_{i,t-1} + \nu_{i,t}$$

Appendix A.4

We perform a simple experiment to back up our intuition that nonlinear models estimated via GMM may need longer time series than those estimated via NLS or similar linear models estimated via OLS:

1. We draw 1024 i.i.d. observations of $x \sim U(0;1)$;
2. We draw 100 independent sets of 1024 i.i.d. observations of $\varepsilon_j \sim N(0;1)$, $j = 1, \dots, 100$;
3. For every set $j = 1, \dots, 100$, we create:
   a. $y_{1,j} = 1.14506 * (3.616314 * x)^{0.5} + \varepsilon_j$
   b. $y_{2,j} = \ln 1.14506 + 0.5 * \ln(3.616314 * x) + \varepsilon_j$
   c. $y_{3,j} = 1.14506 + 0.5 * (3.616314 * x) + \varepsilon_j$
   d. $y_{4,j} = 0.5448326 * (3.616314 * x)^2 + \varepsilon_j$
   e. $y_{5,j} = \ln 0.5448326 + 2 * \ln(3.616314 * x) + \varepsilon_j$
   f. $y_{6,j} = 0.5448326 + 2 * (3.616314 * x) + \varepsilon_j$

   The parameters are calibrated so that $Var(y_{1,j}) = Var(y_{2,j}) = Var(y_{3,j})$, $Var(y_{4,j}) = Var(y_{5,j}) = Var(y_{6,j})$ (equalising variances of the explained variables) and $Var(3.616314 * x) = Var(\ln(3.616314 * x))$ (equalising variances of the explanatory variables) with a precision up to 0.000001. It is worth noting, however, that models b. and e. are not log-linearised versions of models a. and d., respectively, since in all cases the error term is additive.

4. For every set we estimate models:
   a. $y_{1,j} = \alpha_1 * (3.616314 * x)^{\beta_1} + \epsilon_{1,j}$ using Nonlinear Least Squares and the Generalised Method of Moments (instruments: constant and explanatory variable)
   b. $y_{2,j} = \alpha_2 + \beta_2 * \ln(3.616314 * x) + \epsilon_{2,j}$ using Ordinary Least Squares
   c. $y_{3,j} = \alpha_3 + \beta_3 * (3.616314 * x) + \epsilon_{3,j}$ using Ordinary Least Squares
   d. $y_{4,j} = \alpha_4 * (3.616314 * x)^{\beta_4} + \epsilon_{4,j}$ using Nonlinear Least Squares and the Generalised Method of Moments (instruments: constant and explanatory variable)
   e. $y_{5,j} = \alpha_5 + \beta_5 * \ln(3.616314 * x) + \epsilon_{5,j}$ using Ordinary Least Squares

f. $y_{6,j} = \alpha_6 + \beta_6 * (3.616314 * x) + \epsilon_{6,j}$ using Ordinary Least Squares

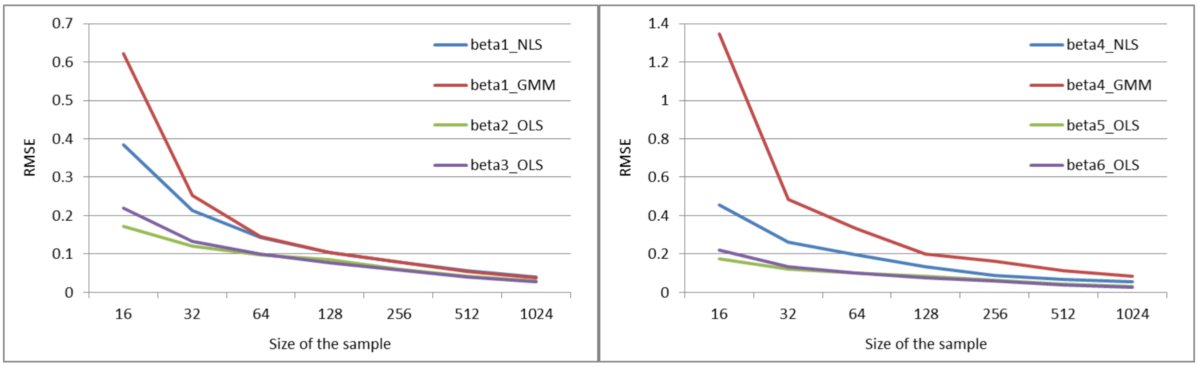
for the first $16, 32, 64, 128, 256, 512$ and 1024 observations of 1024 observations.

5. For every set and every size of the sample, we calculate the root mean squared error:
    a. $RMSE(\hat{\beta}_1^{NLS})$ and $RMSE(\hat{\beta}_1^{GMM})$
    b. $RMSE(\hat{\beta}_2^{OLS})$
    c. $RMSE(\hat{\beta}_3^{OLS})$
    d. $RMSE(\hat{\beta}_4^{NLS})$ and $RMSE(\hat{\beta}_4^{GMM})$
    e. $RMSE(\hat{\beta}_5^{OLS})$
    f. $RMSE(\hat{\beta}_6^{OLS})$

Figure A4.1 presents the root mean squared errors of the estimators as functions of sample size for triplets of models a. – c. (left panel) and d. – f. (right panel). Although the experiment was quite straightforward and based on a relatively small number of replications and sample sizes, it shows that the:

- NLS estimator is more efficient than the GMM one for small sample sizes. As the number of observations goes up, the difference between RMSE of the two estimators diminishes, while the pace of convergence seems to depend on parameterisation of the data-generating process.
- RMSEs of nonlinear model estimators are larger than those of similar linear model estimators. Although the difference between the two decreases as the size of the sample grows, the difference seems to be non-negligible for the number of observations which is typical for macro data.

Figure A4.1 The comparison of RMSEs of different estimators



Source: own calculation

Appendix A.5

Table A5.1 Detailed data information

Tag	Detailed description	Source
	Business cycle and climate	
cu_t	Capacity utilization: total industry, percent of capacity, quarterly average monthly data, seasonally adjusted by data provider	FRED®: http://research.stlouisfed.org/fred2/series/TCU
ai_ma_t	Chicago Fed National Activity Index: three month moving average, index, quarterly average monthly data, seasonally adjusted with X-12-ARIMA	FRED®: http://research.stlouisfed.org/fred2/series/CFNAIMA3#
ai_di_t	Chicago Fed National Activity Index: diffusion index, index, quarterly average monthly data, seasonally adjusted with X-12-ARIMA	FRED®: http://research.stlouisfed.org/fred2/series/CFNAIDIFF#
cs_t	University of Michigan: Consumer Sentiment©, index, 1966q1=100, quarterly average monthly data, seasonally adjusted with X-12-ARIMA	FRED®: http://research.stlouisfed.org/fred2/series/UMCSENT
	Labour market	
ur_t	Civilian unemployment rate, percent, quarterly average monthly data, seasonally adjusted by data provider	FRED®: http://research.stlouisfed.org/fred2/series/UNRATE
$w\&s_t$	Compensation of employees: wages and salaries, billions of dollars, quarterly data, seasonally adjusted annual rate by data provider, annualised percent change from quarter ago	FRED®: http://research.stlouisfed.org/fred2/series/A576RC1Q027SBEA
$lfpr_t$	Civilian labour force participation rate, percent, quarterly average monthly data, seasonally adjusted by data provider	FRED®: http://research.stlouisfed.org/fred2/series/CIVPART
$lmci_t$	Labour Market Conditions Index, index, quarterly average monthly data, seasonally adjusted by data provider	FRED®: http://research.stlouisfed.org/fred2/series/FRBLMCI
	Financial and monetary conditions	
$ccdi_t$	CredAbility Consumer Distress Index, percent, quarterly data, seasonally adjusted with X-12-ARIMA	FRED®: https://research.stlouisfed.org/fred2/series/CCDIOAQ156N
$fcnls_t$	Chicago Fed National Financial Conditions Nonfinancial Leverage Subindex, index, quarterly average weekly data, not seasonally adjusted (identifiable seasonality not present)	FRED®: https://research.stlouisfed.org/fred2/series/NFCINONFINLEVERAGE#
$fcls_t$	Chicago Fed National Financial Conditions Leverage Subindex, index, quarterly average weekly data, not seasonally adjusted (identifiable seasonality not present)	FRED®: https://research.stlouisfed.org/fred2/series/NFCILEVERAGE

$fccs_t$	Chicago Fed National Financial Conditions Credit Subindex, index, quarterly average weekly data, not seasonally adjusted (identifiable seasonality not present)	FRED®: https://research.stlouisfed.org/fred2/series/NFCICREDIT#
$fcrs_t$	Chicago Fed National Financial Conditions Risk Subindex, index, quarterly average weekly data, not seasonally adjusted (identifiable seasonality not present)	FRED®: https://research.stlouisfed.org/fred2/series/NFCIRISK
$afci_t$	Chicago Fed Adjusted National Financial Conditions Index, index, quarterly average weekly data, not seasonally adjusted (identifiable seasonality not present)	FRED®: https://research.stlouisfed.org/fred2/series/ANFCI
fci_t	Chicago Fed National Financial Conditions Index, index, quarterly average weekly data, not seasonally adjusted (identifiable seasonality not present)	FRED®: https://research.stlouisfed.org/fred2/series/NFCI
mb_t	Board of governors monetary base, adjusted for changes in reserve requirements, billions of dollars, quarterly average monthly data, seasonally adjusted by data provider, annualised percent change from quarter ago	FRED®: https://research.stlouisfed.org/fred2/series/BOGAMBSL#
mb_gdp_t	Board of governors monetary base, adjusted for changes in reserve requirements, billions of dollars, quarterly average monthly data, seasonally adjusted by data provider, percent of gross domestic product, billions of dollars, quarterly, seasonally adjusted annual rate by data provider	FRED®: https://research.stlouisfed.org/fred2/series/BOGAMBSL# and https://research.stlouisfed.org/fred2/series/GDP
mzm_t	MZM (money zero maturity) stock, billions of dollars, quarterly average monthly data, seasonally adjusted by data provider, annualised percent change from quarter ago	FRED®: https://research.stlouisfed.org/fred2/series/MZMSL
$m2_t$	M2 money stock, billions of dollars, quarterly average monthly data, seasonally adjusted by data provider, annualised percent change from quarter ago	FRED®: https://research.stlouisfed.org/fred2/series/M2SL
baa_i_t	Moody's seasoned Baa corporate bond minus federal funds rate, percent, quarterly average monthly data, not seasonally adjusted (identifiable seasonality not present)	FRED®: http://research.stlouisfed.org/fred2/series/BAAFFM
aaa_i_t	Moody's seasoned Aaa corporate bond minus federal funds rate, percent, quarterly average monthly data, not seasonally adjusted (identifiable seasonality not present)	FRED®: http://research.stlouisfed.org/fred2/series/AAAFFM
llr_tl_t	Loan loss reserve to total loans for all U.S. banks, percent, quarterly data (end of period), not seasonally adjusted (identifiable seasonality not present)	FRED®: http://research.stlouisfed.org/fred2/series/USLLRTL
fat_t	Failures and assistance transactions of all institutions for the United States and other areas, number of institutions, interpolated from annual data	FRED®: http://research.stlouisfed.org/fred2/series/BNKTTLA641N
nl_tl_t	Nonperforming loans (past due 90+ days plus nonaccrual) to total loans for all U.S. banks, percent, quarterly data (end of period), not seasonally adjusted (identifiable seasonality not present)	FRED®: https://research.stlouisfed.org/fred2/series/USNPTL#
dr_t	Delinquency rate on all loans, all commercial banks, percent, quarterly data (end of period), not seasonally adjusted (identifiable seasonality not present)	FRED®: https://research.stlouisfed.org/fred2/series/DRALACBN
cor_t	Charge-off rate on all loans, all commercial banks, percent, quarterly data, not	FRED®: https://research.stlouisfed.org/fred2/series/CORALACBS#

	seasonally adjusted (identifiable seasonality not present)	
	Uncertainty	
$epui_t$	Economic Policy Uncertainty Index for United States, index by Baker, Bloom and Davis (2013), quarterly average monthly data, seasonally adjusted with X-12-ARIMA	FRED®: http://research.stlouisfed.org/fred2/series/USEPUINDXM
$emeui_t$	Equity Market-related Economic Uncertainty, index by Baker, Bloom and Davis (2013), quarterly average daily data, seasonally adjusted with X-12-ARIMA	FRED®: http://research.stlouisfed.org/fred2/series/WLEMUINDXD
	Globalisation	
$wgdp_t$	World gross domestic product, constant 2005 US dollar, interpolated from annual data, annualised percent change from quarter ago	World DataBank
ws_gdp_t	World gross savings, percent of world gross domestic product, nominal ratio, interpolated from annual data	World DataBank
wds_gdp_t	World gross domestic savings, percent of world gross domestic product, nominal ratio, interpolated from annual data	World DataBank
we_gdp_t	World exports of goods and services, percent of world gross domestic product, nominal ratio, interpolated from annual data	World DataBank
e_gdp_t	Real exports of goods and services, billions of chained 2009 dollars, quarterly data, seasonally adjusted annual rate by data provider, percent of real gross domestic product, billions of chained 2009 dollars, quarterly data, seasonally adjusted annual rate by data provider	FRED®: http://research.stlouisfed.org/fred2/series/EXPGSC1# and http://research.stlouisfed.org/fred2/series/GDPC1
i_gdp_t	Real imports exports of goods and services, billions of chained 2009 dollars, quarterly data, seasonally adjusted annual rate by data provider, percent of real gross domestic product, billions of chained 2009 dollars, quarterly data, seasonally adjusted annual rate by data provider	FRED®: http://research.stlouisfed.org/fred2/series/IMPGSC1# and http://research.stlouisfed.org/fred2/series/GDPC1
ca_gdp_t	Balance on current account, billions of dollars, quarterly, seasonally adjusted by data provider, percent of gross domestic product, billions of dollars, quarterly, seasonally adjusted annual rate by data provider	FRED®: http://research.stlouisfed.org/fred2/series/BOPBCA and https://research.stlouisfed.org/fred2/series/GDP
aa_gdp_t	U.S. assets abroad, net: outflow (-), billions of dollars, quarterly, seasonally adjusted by data provider, percent of gross domestic product, billions of dollars, quarterly data, seasonally adjusted annual rate by data provider	FRED®: http://research.stlouisfed.org/fred2/series/BOPO# and https://research.stlouisfed.org/fred2/series/GDP
fa_gdp_t	Foreign assets in the U.S., net: capital inflow (+), billions of dollars, quarterly, seasonally adjusted by data provider, percent of gross domestic product, billions of dollars, quarterly, seasonally adjusted annual rate by data provider	FRED®: https://research.stlouisfed.org/fred2/series/BOPI# and https://research.stlouisfed.org/fred2/series/GDP
usd_t	Trade weighted U.S. dollar index: major Currencies, index march 1973=100, quarterly average daily data, not seasonally adjusted (identifiable seasonality not	FRED®: https://research.stlouisfed.org/fred2/series/DTWEXM#

	present), annualised percent change from quarter ago	
	Structural changes – structure of the economy	
$lshare_t$	Nonfarm business sector: labour share, index, 2009=100, quarterly data, seasonally adjusted by data provider	FRED®: http://research.stlouisfed.org/fred2/series/PRS85006173#
sva_gdp_t	Services, etc., value added: percent of gross domestic product, nominal ratio, quarterly interpolated from annual data	World DataBank
	Structural changes – potential growth and development	
gdp_pot_t	Real potential gross domestic product, billions of chained 2009 dollars, not seasonally adjusted (identifiable seasonality not present), annualised percent change from quarter ago	FRED®: http://research.stlouisfed.org/fred2/series/GDPPOT#
rd_gdp_t	Gross domestic product: research and development, billions of chained 2009 dollars, quarterly data, seasonally adjusted annual rate by data provider, percent of real gross domestic product, billions of chained 2009 dollars, quarterly data, seasonally adjusted annual rate by data provider	FRED®: http://research.stlouisfed.org/fred2/series/Y694RX1Q020SBEA and http://research.stlouisfed.org/fred2/series/GDPC1
rd_t	Gross domestic product: research and development, billions of chained 2009 dollars, quarterly data, seasonally adjusted annual rate by data provider, annualised percent change from quarter ago	FRED®: http://research.stlouisfed.org/fred2/series/Y694RX1Q020SBEA
pa_r_t	Patent applications, residents, quarterly interpolated from annual data, annualised percent change from quarter ago	World DataBank
pa_rn_t	Patent applications, residents + nonresidents, quarterly interpolated from annual data, annualised percent change from quarter ago	World DataBank
$stja_t$	Scientific and technical journal articles, quarterly interpolated from annual data, annualised percent change from quarter ago	World DataBank
	Structural changes – financial development	
mzm_gdp_t	MZM (money zero maturity) stock, billions of dollars, quarterly average monthly data, seasonally adjusted by data provider, percent of gross domestic product, billions of dollars, quarterly, seasonally adjusted annual rate by data provider	FRED®: https://research.stlouisfed.org/fred2/series/MZMSL and https://research.stlouisfed.org/fred2/series/GDP
$m2\_gdp_t$	M2 money stock, billions of dollars, quarterly average monthly data, seasonally adjusted by data provider, percent of gross domestic product, billions of dollars, quarterly, seasonally adjusted annual rate by data provider	FRED®: https://research.stlouisfed.org/fred2/series/M2SL and https://research.stlouisfed.org/fred2/series/GDP
ta_gdp_t	Total assets at all commercial banks, billions of dollars, quarterly average monthly data, seasonally adjusted by data provider, percent of gross domestic product, billions of dollars, quarterly data, seasonally adjusted annual rate by data provider	FRED®: http://research.stlouisfed.org/fred2/series/TLAACBM027SBOG and https://research.stlouisfed.org/fred2/series/GDP
bc_gdp_t	Bank credit at all commercial banks, billions of dollars, quarterly average weekly	FRED®: http://research.stlouisfed.org/fred2/series/TOTBKCR# and

	data, seasonally adjusted by data provider, percent of gross domestic product, billions of dollars, quarterly data, seasonally adjusted annual rate by data provider	https://research.stlouisfed.org/fred2/series/GDP
bc_d_t	Bank credit at all commercial banks, billions of dollars, quarterly average weekly data, seasonally adjusted by data provider, percent of deposits of all commercial banks, billions of dollars, quarterly average monthly data, seasonally adjusted by data provider	FRED®: http://research.stlouisfed.org/fred2/series/TOTBKCR# and http://research.stlouisfed.org/fred2/series/DPSACBM027SBOG
cl_gdp_t	Consumer loans at all commercial banks, billions of dollars, quarterly average monthly data, seasonally adjusted by data provider, percent of gross domestic product, billions of dollars, quarterly data, seasonally adjusted annual rate by data provider	FRED®: http://research.stlouisfed.org/fred2/series/CONSUMER# and https://research.stlouisfed.org/fred2/series/GDP
rel_gdp_t	Real estate loans at all commercial banks, billions of dollars, quarterly average monthly data, seasonally adjusted by data provider, percent of gross domestic product, billions of dollars, quarterly data, seasonally adjusted annual rate by data provider	FRED®: http://research.stlouisfed.org/fred2/series/REALLN# and https://research.stlouisfed.org/fred2/series/GDP
mf_gdp_t	Money market mutual funds: total financial assets, billions of dollars, quarterly data, seasonally adjusted with X-12-ARIMA, percent of gross domestic product, billions of dollars, quarterly data, seasonally adjusted annual rate by data provider	FRED®: http://research.stlouisfed.org/fred2/series/MMMFFAQ027S# and https://research.stlouisfed.org/fred2/series/GDP
tas_ta_t	Treasury and agency securities at all commercial banks, billions of dollars, quarterly average monthly data, seasonally adjusted by data provider, percent of total assets of all commercial banks, billions of dollars, quarterly average monthly data, seasonally adjusted by data provider	FRED®: http://research.stlouisfed.org/fred2/series/USGSEC# and http://research.stlouisfed.org/fred2/series/TLAACBM027SBOG
ltd_d_t	Large time deposits at all commercial banks, billions of dollars, quarterly average monthly data, seasonally adjusted by data provider, percent of deposits of all commercial banks, billions of dollars, quarterly average monthly data, seasonally adjusted by data provider	FRED®: http://research.stlouisfed.org/fred2/series/LTDACBM027SBOG and http://research.stlouisfed.org/fred2/series/DPSACBM027SBOG
nfb_cb_t	Total assets of nonfinancial corporate business, billions of dollars, quarterly data, not seasonally adjusted (identifiable seasonality not present), percent of total assets of all commercial banks, billions of dollars, quarterly average monthly data, seasonally adjusted by data provider	FRED®: http://research.stlouisfed.org/fred2/series/TABSNNCB# and http://research.stlouisfed.org/fred2/series/TLAACBM027SBOG
nim_t	Net interest margin for all U.S. banks, percent (ratio of tax-adjusted income to average earning assets), quarterly data, not seasonally adjusted (identifiable seasonality not present)	FRED®: http://research.stlouisfed.org/fred2/series/USNIM
roa_t	Return on average assets for all U.S. banks, percent (net income call to quarterly average of total assets), quarterly data, not seasonally adjusted (identifiable seasonality not present)	FRED®: http://research.stlouisfed.org/fred2/series/USROA
$stck\_gdp_t$	Wilshire 5000 Full Cap Price Index©, index, quarterly average daily data, not seasonally adjusted (identifiable seasonality not present), percent of gross domestic	FRED®: http://research.stlouisfed.org/fred2/series/WILL5000PRFC and https://research.stlouisfed.org/fred2/series/GDP

	product, billions of dollars, quarterly data, seasonally adjusted annual rate by data provider	
	Greenspan standard	
$sp500_t$	S&P 500©, index, quarterly average daily data, not seasonally adjusted (identifiable seasonality not present), annualised percent change from quarter ago	Stooq: http://stooq.com/q/d/?s=^spx&d1=19790101&d2=20141205&c=0
$nasd_t$	NASDAQ Composite Index©, index, 5 February 1971 = 100, quarterly average daily data, not seasonally adjusted (identifiable seasonality not present), annualised percent change from quarter ago	FRED®: https://research.stlouisfed.org/fred2/series/NASDAQCOM
$wilsh_t$	Wilshire 5000 Full Cap Price Index©, index, quarterly average daily data, not seasonally adjusted (identifiable seasonality not present), annualised percent change from quarter ago	FRED®: http://research.stlouisfed.org/fred2/series/WILL5000PRFC
djc_t	Dow Jones Composite©, index, quarterly average daily data, not seasonally adjusted (identifiable seasonality not present), annualised percent change from quarter ago	Stooq: http://stooq.com/q/d/?s=^djc&c=0&d1=19810101&d2=20141205
$djia_t$	Dow Jones Industrial Average©, index, quarterly average daily data, not seasonally adjusted (identifiable seasonality not present), annualised percent change from quarter ago	Stooq: http://stooq.com/q/d/?s=^dji&c=0&d1=19790101&d2=20141205
$nasd100_t$	NASDAQ 100©, index, quarterly average daily data, not seasonally adjusted (identifiable seasonality not present), annualised percent change from quarter ago	Stooq: http://stooq.com/q/d/?s=^ndx&i=d&d1=19790101&d2=20141205&l=184
$spcs_t$	S&P/Case-Shiller U.S. National Home Price Index©, index, 2010q1 = 100, quarterly data, not seasonally adjusted (identifiable seasonality not present), annualised percent change from quarter ago	FRED®: https://research.stlouisfed.org/fred2/series/USCSCOMHPISA
hpi_t	All-transactions house price index (US. Federal Housing Finance Agency), index, 1980q1 = 100, quarterly data, not seasonally adjusted (identifiable seasonality not present), annualised percent change from quarter ago	FRED®: https://research.stlouisfed.org/fred2/series/USSTHPI#
wti_t	Spot oil price: West Texas Intermediate©, dollars per barrel, quarterly average monthly data, not seasonally adjusted (identifiable seasonality not present), annualised percent change from quarter ago	FRED®: https://research.stlouisfed.org/fred2/series/OILPRICE#
cpe_t	World Bank commodity price data: energy, index, 2010 = 100, quarterly average monthly data, not seasonally adjusted (identifiable seasonality not present), annualised percent change from quarter ago	Worldbank Pink Data: http://siteresources.worldbank.org/INTPROSPECTS/Resources/334934-1304428586133/pink_data_m.xlsx
$cpne_t$	World Bank commodity price data: nonenergy, index, 2010 = 100, quarterly average monthly data, not seasonally adjusted (identifiable seasonality not present), annualised percent change from quarter ago	Worldbank Pink Data: http://siteresources.worldbank.org/INTPROSPECTS/Resources/334934-1304428586133/pink_data_m.xlsx
	Greenspan conundrum	

$t10y\_3m_t$	10-year treasury constant maturity rate minus 3-month treasury constant maturity rate, percent, quarterly data	FRED®: http://research.stlouisfed.org/fred2/series/T10Y3M#
$t10y\_ffr_t$	10-year treasury constant maturity rate minus federal funds rate, percent, quarterly data	FRED®: http://research.stlouisfed.org/fred2/series/T10YFF

Appendix A.6

Table A6.1 Suggested functional forms when modelling nonlinearity

z_{kt}^{j}	inflation equation				output gap equation				interest rate equation			
	Maximum power $J = 3$		Maximum power $J = 4$		Maximum power $J = 3$		Maximum power $J = 4$		Maximum power $J = 3$		Maximum power $J = 4$	
	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2
π_{t-1}	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN
x_{t-1}	LIN	LIN	LIN	LIN	LIN	LIN	L1	L1	LIN	LIN	LIN	LIN
i_{t-1}	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN
π_t	-	-	-	-	-	-	-	-	LIN	LIN	LIN	LIN
x_t	-	-	-	-	-	-	-	-	LIN	LIN	LIN	LIN

Table A6.2 Suggested functional forms when modelling indirect forms of nonlinearity

s_{kt}^{j}	inflation equation				output gap equation				interest rate equation			
	Maximum power $J = 3$		Maximum power $J = 4$		Maximum power $J = 3$		Maximum power $J = 4$		Maximum power $J = 3$		Maximum power $J = 4$	
	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2
					Sample mean of model variables							
π_{t-1}^{SM}	LIN	LIN	LIN	LIN	LIN	LIN	L2/E	L1	LIN	LIN	LIN	LIN
x_{t-1}^{SM}	LIN	LIN	LIN	LIN	L1	L1	L1	L1	LIN	LIN	LIN	LIN
i_{t-1}^{SM}	L2/E	L2/E	L2/E	L2/E	LIN	LIN	LIN	LIN	L1	L1	L2/E	L2/E
					Sample variance of model variables							
π_{t-1}^{SV}	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN
x_{t-1}^{SV}	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	L2/E	L1	L2/E	L2/E
i_{t-1}^{SV}	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN

Table A6.3 Suggested functional forms when modelling state-dependency with respect to measures of business cycle and climate

s_{kt}^{j}	inflation equation				output gap equation				interest rate equation			
	Maximum power $J = 3$		Maximum power $J = 4$		Maximum power $J = 3$		Maximum power $J = 4$		Maximum power $J = 3$		Maximum power $J = 4$	
	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2
cu_t	LIN	LIN	LIN	LIN	L1	L1	L1	L1	L1	L1	L2/E	L2/E
ai_ma_t	LIN	LIN	LIN	LIN	L1	L1	L2/E	L2/E	L1	L1	L2/E	L2/E
ai_di_t	LIN	LIN	LIN	LIN	L1	L1	L2/E	L2/E	L1	L1	L1	L1
cs_t	LIN	LIN	LIN	LIN	L1	L1	L1	L1	L1	L1	L1	L1

Table A6.4 Suggested functional forms when modelling state-dependency with respect to measures of labour market conditions

s_{kt}^{j}	inflation equation				output gap equation				interest rate equation			
	Maximum power $J=3$		Maximum power $J=4$		Maximum power $J=3$		Maximum power $J=4$		Maximum power $J=3$		Maximum power $J=4$	
	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2
ur_t	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN
$w\&s_t$	L1	L1	L2/E	L2/E	L1	L1	LIN	LIN	LIN	LIN	LIN	LIN
$lfpr_t$	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN
$lmci_t$	LIN	LIN	LIN	LIN	L1	L1	L1	L1	L1	L1	L1	L1

Table A6.5 Suggested functional forms when modelling state-dependency with respect to measures of financial conditions

s_{kt}^{j}	inflation equation				output gap equation				interest rate equation			
	Maximum power $J=3$		Maximum power $J=4$		Maximum power $J=3$		Maximum power $J=4$		Maximum power $J=3$		Maximum power $J=4$	
	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2
	Indices of financial conditions											
$ccdi_t$	L1	L1	LIN	LIN	L1	L1	L2/E	L2/E	L1	L1	L1	L1
$fcnls_t$	LIN	LIN	L2/E	L2/E	LIN	LIN	LIN	LIN	L2/E	L2/E	L2/E	L2/E
$fcls_t$	LIN	LIN	LIN	LIN	L1	L1	L2/E	L2/E	L2/E	L2/E	L2/E	L2/E
$fccs_t$	L1	L1	L2/E	L2/E	L1	L1	L1	L1	LIN	LIN	LIN	LIN
$fcrs_t$	L2/E	L2/E	L2/E	L2/E	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN
$afci_t$	L1	L1	L1	L1	LIN	LIN	LIN	LIN	L2/E	L1	L2/E	L2/E
fci_t	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN
	Monetary aggregates											
mb_t	L1	L1	LIN	LIN	L1	L1	L1	L1	LIN	LIN	LIN	LIN
mb_gdp_t	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN
mzm_t	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	L1	L1	L1	L1
$m2_t$	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	L1	L1	L2/E	L2/E
	Interest rate quality spreads											
baa_i_t	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN
aaa_i_t	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN
	Quality of credit portfolio											
llr_tl_t	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	L1	L1	LIN	LIN
fat_t	L1	L1	L1	L1	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN
nl_tl_t	L1	L1	L1	L1	L1	L1	L2/E	L2/E	L1	L1	L1	L1
dr_t	L1	L1	L1	L1	L1	L1	L1	L1	L1	L1	L1	L1
cor_t	LIN	LIN	LIN	LIN	L1	L1	L1	L1	LIN	LIN	LIN	LIN

Table A6.6 Suggested functional forms when modelling state-dependency with respect to measures of uncertainty

s_{kt}^{j}	inflation equation				output gap equation				interest rate equation			
	Maximum power $J=3$		Maximum power $J=4$		Maximum power $J=3$		Maximum power $J=4$		Maximum power $J=3$		Maximum power $J=4$	
	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2
$epui_t$	LIN	LIN	LIN	LIN	L1	L1	L2/E	L2/E	L1	L1	LIN	LIN
$emeui_t$	LIN	LIN	LIN	LIN	LIN	LIN	L1	L1	L1	L1	L1	L1

Table A6.7 Suggested functional forms when modelling state-dependency with respect to measures of globalisation

s_{kt}^{j}	inflation equation				output gap equation				interest rate equation			
	Maximum power $J=3$		Maximum power $J=4$		Maximum power $J=3$		Maximum power $J=4$		Maximum power $J=3$		Maximum power $J=4$	
	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2
World data												
$wgdp_t$	LIN	LIN	LIN	LIN	LIN	L1	LIN	LIN	L1	L1	LIN	LIN
ws_gdp_t	L1	L1	LIN	LIN	L2/E	L2/E	LIN	LIN	LIN	LIN	LIN	LIN
wds_gdp_t	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN
we_gdp_t	LIN	LIN	LIN	LIN	LIN	L1	L1	L1	L1	L1	LIN	LIN
U.S. data												
e_gdp_t	LIN	L1	LIN	LIN	LIN	LIN	LIN	LIN	L2/E	L2/E	LIN	LIN
i_gdp_t	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN
ca_gdp_t	L1	L1	L1	L1	L1	L1	L2/E	L2/E	LIN	LIN	LIN	LIN
aa_gdp_t	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN
fa_gdp_t	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN
usd_t	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN

Table A6.8 Suggested functional forms when modelling state-dependency with respect to measures of composition of the economy

s_{kt}^{j}	inflation equation				output gap equation				interest rate equation			
	Maximum power $J=3$		Maximum power $J=4$		Maximum power $J=3$		Maximum power $J=4$		Maximum power $J=3$		Maximum power $J=4$	
	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2
$lshare_t$	LIN	LIN	LIN	LIN	L1	L1	L1	L1	L1	L1	L1	L1
sva_gdp_t	LIN	LIN	LIN	LIN	L1	L1	L1	L1	LIN	LIN	LIN	LIN

Table A6.9 Suggested functional forms when modelling state-dependency with respect to measures of potential growth and development

s_{kt}^{j}	inflation equation				output gap equation				interest rate equation			
	Maximum power $J=3$		Maximum power $J=4$		Maximum power $J=3$		Maximum power $J=4$		Maximum power $J=3$		Maximum power $J=4$	
	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2
gdp_pot_t	L1	L1	L1	L1	L1	L1	L1	L1	L2/E	L2/E	L2/E	L2/E
rd_gdp_t	L1	L1	L1	L1	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN
rd_t	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN
pa_r_t	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN
pa_rn_t	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN

Table A6.10 Suggested functional forms when modelling state-dependency with respect to measures of financial development

s_{kt}^{j}	inflation equation				output gap equation				interest rate equation			
	Maximum power $J = 3$		Maximum power $J = 4$		Maximum power $J = 3$		Maximum power $J = 4$		Maximum power $J = 3$		Maximum power $J = 4$	
	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2
Money supply to GDP ratios												
mzm_gdp_t	L1	L1	L1	L1	L1	L1	L2/E	L2/E	LIN	LIN	LIN	LIN
$m2\_gdp_t$	L1	L1	L1	L1	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN
Bank assets ratios												
ta_gdp_t	L1	L1	L1	L1	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN
bc_gdp_t	L1	L1	L1	L1	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN
bc_d_t	L1	L1	L1	L1	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN
md_gdp_t	L1	L1	L1	L1	L1	L1	L2/E	L2/E	L1	L1	L1	L1
cl_gdp_t	LIN	LIN	LIN	LIN	LIN	LIN	L1	L1	LIN	LIN	LIN	LIN
rel_gdp_t	L1	L1	L1	L1	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN
tas_ta_t	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN
ltd_d_t	L1	L1	L1	L1	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN
nfb_cb_t	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	L1	L1
Other measures												
mf_gdp_t	LIN	LIN	LIN	LIN	L1	L1	L2/E	L2/E	L1	L1	L1	L1
nim_t	L2/E	L2/E	L2/E	L2/E	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN
roa_t	LIN	LIN	L1	L1	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN
$stck\_gdp_t$	L1	L1	L1	L1	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN

Table A6.11 P-values of tests for state-dependency with respect to variables related to 'Greenspan conundrum'

s_{kt}^{j}	inflation equation				output gap equation				interest rate equation			
	Maximum power $J = 3$		Maximum power $J = 4$		Maximum power $J = 3$		Maximum power $J = 4$		Maximum power $J = 3$		Maximum power $J = 4$	
	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2
$t10y\_3m_t$	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	L1	L1	L1	L1
$t10y\_ffr_t$	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	L1	L1	L1	L1

Table A6.12 P-values of tests for state-dependency with respect to variables related to 'Greenspan standard'

s_{kt}^{j}	inflation equation				output gap equation				interest rate equation			
	Maximum power $J = 3$		Maximum power $J = 4$		Maximum power $J = 3$		Maximum power $J = 4$		Maximum power $J = 3$		Maximum power $J = 4$	
	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2
Stock prices												
$sp500_t$	LIN	LIN	LIN	LIN	L1	L1	L2/E	L2/E	LIN	LIN	LIN	LIN
$nasd_t$	LIN	LIN	LIN	LIN	LIN	LIN	L1	L1	LIN	LIN	LIN	LIN
$wilsh_t$	LIN	LIN	LIN	LIN	L1	L1	L2/E	L2/E	LIN	LIN	LIN	LIN
djc_t	LIN	LIN	LIN	LIN	L1	L1	LIN	LIN	LIN	LIN	LIN	LIN
$djia_t$	LIN	LIN	LIN	LIN	L1	L1	L2/E	L2/E	LIN	LIN	LIN	LIN
$nasd100_t$	LIN	LIN	L2/E	L2/E	L1	L1	LIN	LIN	LIN	LIN	LIN	LIN
Real estate prices												
$spcs_t$	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	L2/E	L2/E	L2/E	L2/E
hpi_t	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN
Commodity prices												
wti_t	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	L1	L1	L1	L1
cpe_t	LIN	L1	LIN	LIN	LIN	LIN	L1	L1	LIN	LIN	LIN	LIN
$cpme_t$	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN	LIN

Appendix A.7

Table A7.1 Final estimates of $STAR$ model when modelling nonlinearity (standard errors in square brackets)

y_t	s_t	$G(s_t;\gamma,\boldsymbol{c})$	φ_{21}	φ_{22}	φ_{23}	φ_{24}	ψ_{21}	ψ_{22}	ψ_{23}	ψ_{24}	γ	$\boldsymbol{c}$	φ_{25}
x_t	x_{t-1}	$LSTAR1$	-0.311 [0.618]	-0.037 [0.093]	0.514 [0.197]	0.014 [0.115]	2.979 [1.132]	1.174 [0.308]	-	-0.781 [0.202]	32	p_{81}	0.814 [0.165]

Table A7.2 Final estimates of $STAR$ model when modelling indirect forms of nonlinearity (standard errors in square brackets)

y_t	s_t	$G(s_t;\gamma,\boldsymbol{c})$	$\varphi_{\dots1}$	$\varphi_{\dots2}$	$\varphi_{\dots3}$	$\varphi_{\dots4}$	$\psi_{\dots1}$	$\psi_{\dots2}$	$\psi_{\dots3}$	$\psi_{\dots4}$	γ	$\boldsymbol{c}$	$\varphi_{\dots5}$
π_t	i_{t-1}^{SM}	$LSTAR1$	0.945 [0.282]	0.766 [0.093]	0.070 [0.034]	-0.101 [0.035]	8.651 [2.078]	-0.668 [0.239]	0.572 [0.169]	-0.661 [0.217]	32	p_{82}	-0.329 [0.137]
x_t	x_{t-1}^{SM}	$LSTAR1$	0.156 [0.807]	-0.269 [0.115]	0.176 [0.132]	-0.156 [0.134]	-	1.801 [0.422]	-	-	1.5	p_{91}	0.911 [0.080]
i_t	x_{t-1}^{SV}	$LSTAR1$	0.694 [0.518]	0.110 [0.056]	0.189 [0.064]	0.813 [0.106]	-	-	-1.125 [0.257]	-0.516 [0.106]	10	p_{94}	0.816 [0.135]

Table A7.3 Final estimates of $STAR$ model when modelling state-dependency with respect to measures of business cycle and climate (standard errors in square brackets)

y_t	s_t	$G(s_t;\gamma,\boldsymbol{c})$	$\varphi_{\dots1}$	$\varphi_{\dots2}$	$\varphi_{\dots3}$	$\varphi_{\dots4}$	$\psi_{\dots1}$	$\psi_{\dots2}$	$\psi_{\dots3}$	$\psi_{\dots4}$	γ	$\boldsymbol{c}$	$\varphi_{\dots5}$
x_t	cu_t	$LSTAR1$	-0.031 [0.188]	-0.211 [0.068]	0.855 [0.058]	0.032 [0.031]	-	0.250 [0.049]	0.147 [0.069]	-	32	p_{35}	0.022 [0.133]
	ai_ma_t	$ESTAR$	0.184 [0.141]	-0.448 [0.070]	0.804 [0.109]	0.005 [0.023]	-	0.443 [0.060]	0.216 [0.128]	-	0.7	p_7	-0.150 [0.126]
	ai_di_t	$LSTAR1$	0.160 [0.150]	-0.501 [0.084]	0.985 [0.032]	0.007 [0.025]	-	0.498 [0.077]	-	-	2.7	p_{10}	-0.124 [0.127]
	cs_t	$LSTAR1$	0.655 [0.671]	-0.160 [0.110]	0.690 [0.218]	-0.033 [0.128]	-1.082 [0.343]	0.211 [0.126]	-0.155 [0.059]	-	32	p_{55}	0.839 [0.170]
i_t	cu_t	$LSTAR1$	0.192 [0.205]	-0.990 [0.179]	-0.207 [0.203]	0.960 [0.034]	-	1.105 [0.174]	0.340 [0.221]	-	1.9	p_5	0.519 [0.120]
	ai_ma_t	$LSTAR1$	-2.249 [0.370]	0.084 [0.047]	0.105 [0.034]	0.950 [0.027]	2.725 [0.368]	-	-	-	0.8	p_5	0.425 [0.117]
	ai_di_t	$LSTAR1$	0.168 [0.236]	-0.401 [0.097]	0.132 [0.046]	0.918 [0.042]	-	0.536 [0.089]	-	-	14.5	p_6	0.614 [0.112]

Table A7.4 Final estimates of $STAR$ model when modelling state-dependency with respect to measures of labour market conditions (standard errors in square brackets)

y_t	s_t	$G(s_t;\gamma,\boldsymbol{c})$	$\varphi_{\dots1}$	$\varphi_{\dots2}$	$\varphi_{\dots3}$	$\varphi_{\dots4}$	$\psi_{\dots1}$	$\psi_{\dots2}$	$\psi_{\dots3}$	$\psi_{\dots4}$	γ	$\boldsymbol{c}$	$\varphi_{\dots5}$
x_t	$w\&s_t$	$LSTAR1$	0.184 [0.324]	-0.049 [0.086]	1.978 [0.265]	-0.028 [0.055]	-	-	-1.733 [0.351]	-	0.3	p_5	0.544 [0.165]
x_t	$lmci_t$	$LSTAR1$	-0.865 [0.238]	-0.016 [0.057]	0.996 [0.033]	-0.010 [0.025]	1.069 [0.165]	-	-	-	17.3	p_{11}	-0.077 [0.127]
i_t	$lmci_t$	$LSTAR1$	-1.589 [0.628]	-0.476 [0.241]	0.144 [0.053]	1.361 [0.157]	1.857 [0.548]	0.606 [0.247]	-	-0.463 [0.150]	22.8	p_{11}	0.632 [0.126]

Table A7.5 Final estimates of $STAR$ model when modelling state-dependency with respect to measures of financial conditions (standard errors in square brackets)

y_t	s_t	$G(s_t;\gamma,\boldsymbol{c})$	$\varphi_{\dots 1}$	$\varphi_{\dots 2}$	$\varphi_{\dots 3}$	$\varphi_{\dots 4}$	$\psi_{\dots 1}$	$\psi_{\dots 2}$	$\psi_{\dots 3}$	$\psi_{\dots 4}$	γ	$\boldsymbol{c}$	$\varphi_{\dots 5}$
π_t	$fcrs_t$	$LSTAR2$	0.667 [0.176]	0.809 [0.067]	0.055 [0.036]	-0.059 [0.026]	-	-	0.154 [0.079]	0.122 [0.027]	27.4	p_{20} p_{87}	-0.349 [0.118]
x_t	$ccdi_t$	$ESTAR$	0.127 [0.198]	-0.037 [0.069]	0.948 [0.044]	-0.176 [0.048]	-	-	-	0.178 [0.041]	32	p_{14}	0.128 [0.134]
	$fcls_t$	$LSTAR1$	-6.658 [1.038]	-0.129 [0.053]	-0.052 [0.210]	1.283 [0.200]	8.801 [1.309]	-	1.217 [0.254]	-1.628 [0.248]	0.8	p_5	-0.193 [0.127]
	$fccs_t$	$LSTAR1$	0.072 [0.168]	0.047 [0.065]	0.942 [0.037]	-0.009 [0.031]	-	-1.224 [0.501]	-	0.361 [0.246]	1.9	p_{95}	-0.042 [0.130]
	mb_t	$LSTAR1$	-10.74 [2.813]	5.346 [1.080]	0.918 [0.047]	-0.008 [0.034]	23.68 [6.086]	-11.75 [2.349]	-	-	0.1	p_{95}	0.209 [0.130]
	nl_tl_t	$LSTAR1$	0.091 [0.188]	-0.012 [0.066]	0.953 [0.048]	-0.003 [0.031]	-	-	-0.368 [0.112]	-0.220 [0.046]	32	p_{86}	0.030 [0.134]
	dr_t	$LSTAR1$	0.170 [0.142]	-0.005 [0.053]	1.026 [0.039]	-0.001 [0.024]	-	-0.526 [0.077]	-0.514 [0.105]	-	4.6	p_{85}	-0.275 [0.125]
i_t	$ccdi_t$	$LSTAR1$	0.108 [0.429]	0.065 [0.060]	0.165 [0.062]	0.868 [0.075]	0.472 [0.125]	-	-	-	32	p_{15}	0.724 [0.126]
	mzm_t	$LSTAR1$	0.426 [0.187]	0.141 [0.035]	0.108 [0.023]	1.013 [0.037]	-1.827 [0.645]	-	-	-0.258 [0.126]	0.6	p_{95}	0.301 [0.127]
	$m2_t$	$LSTAR1$	0.981 [0.438]	0.022 [0.050]	0.197 [0.059]	0.848 [0.092]	-	-	-	-0.243 [0.037]	0.9	p_{84}	0.872 [0.088]

Table A7.6 Final estimates of $STAR$ model when modelling state-dependency with respect to measures of uncertainty (standard errors in square brackets)

y_t	s_t	$G(s_t;\gamma,\boldsymbol{c})$	$\varphi_{\dots 1}$	$\varphi_{\dots 2}$	$\varphi_{\dots 3}$	$\varphi_{\dots 4}$	$\psi_{\dots 1}$	$\psi_{\dots 2}$	$\psi_{\dots 3}$	$\psi_{\dots 4}$	γ	$\boldsymbol{c}$	$\varphi_{\dots 5}$
x_t	$epui_t$	$LSTAR1$	0.292 [0.130]	-0.021 [0.050]	1.004 [0.028]	-0.023 [0.022]	-1.110 [0.147]	-	-	-	29.6	p_{89}	-0.235 [0.125]
	$emeui_t$	$LSTAR1$	-0.318 [0.788]	0.025 [0.090]	0.354 [0.133]	0.001 [0.123]	-	-	0.288 [0.073]	-	20.1	p_{75}	0.902 [0.072]

Table A7.7 Final estimates of $STAR$ model when modelling state-dependency with respect to measures of globalisation (standard errors in square brackets)

y_t	s_t	$G(s_t;\gamma,\boldsymbol{c})$	$\varphi_{\dots 1}$	$\varphi_{\dots 2}$	$\varphi_{\dots 3}$	$\varphi_{\dots 4}$	$\psi_{\dots 1}$	$\psi_{\dots 2}$	$\psi_{\dots 3}$	$\psi_{\dots 4}$	γ	$\boldsymbol{c}$	$\varphi_{\dots 5}$
x_t	ws_gdp_t	$LSTAR1$	-0.480 [0.847]	1.066 [0.283]	0.370 [0.135]	-0.202 [0.175]	-	-1.0878 [0.295]	-	0.224 [0.138]	4	p_{14}	0.921 [0.061]
	ca_gdp_t	$ESTAR$	-0.007 [0.280]	-0.017 [0.083]	1.177 [0.113]	0.150 [0.066]	-	-	-0.333 [0.111]	-0.169 [0.046]	32	p_{71}	0.423 [0.146]
i_t	$wgdp_t$	$LSTAR1$	-2.064 [1.006]	-0.610 [0.249]	-0.256 [0.121]	1.525 [0.235]	2.661 [0.952]	0.700 [0.255]	0.482 [0.110]	-0.672 [0.226]	32	p_9	0.726 [0.122]
	we_gdp_t	$LSTAR1$	-8.437 [3.904]	-0.044 [0.060]	-2.493 [0.766]	3.823 [0.779]	18.624 [7.372]	-	5.202 [1.47]	-5.894 [1.456]	0.1	p_{25}	0.831 [0.093]
	e_gdp_t	$LSTAR2$	0.694 [0.533]	0.101 [0.063]	-0.524 [0.260]	0.814 [0.106]	-	-	0.746 [0.246]	-	32	p_5	0.811 [0.122]

Table A7.8 Final estimates of $STAR$ model when modelling state-dependency with respect to measures of composition of the economy (standard errors in square brackets)

y_t	s_t	$G(s_t;\gamma,\boldsymbol{c})$	$\varphi_{\dots1}$	$\varphi_{\dots2}$	$\varphi_{\dots3}$	$\varphi_{\dots4}$	$\psi_{\dots1}$	$\psi_{\dots2}$	$\psi_{\dots3}$	$\psi_{\dots4}$	γ	$\boldsymbol{c}$	$\varphi_{\dots5}$
x_t	$lshare_t$	$LSTAR1$	-0.092 [0.804]	-0.043 [0.078]	0.457 [0.104]	0.157 [0.117]	-1.593 [1.012]	-	-	-0.171 [0.180]	1.1	p_{81}	0.925 [0.051]
	sva_gdp_t	$LSTAR1$	0.362 [0.143]	-0.041 [0.054]	0.985 [0.031]	-0.024 [0.024]	-	-0.352 [0.049]	-	-	32	p_{83}	-0.095 [0.126]

Table A7.9 Final estimates of $STAR$ model when modelling state-dependency with respect to measures of potential growth and development (standard errors in square brackets)

y_t	s_t	$G(s_t;\gamma,\boldsymbol{c})$	$\varphi_{\dots1}$	$\varphi_{\dots2}$	$\varphi_{\dots3}$	$\varphi_{\dots4}$	$\psi_{\dots1}$	$\psi_{\dots2}$	$\psi_{\dots3}$	$\psi_{\dots4}$	γ	$\boldsymbol{c}$	$\varphi_{\dots5}$
π_t	gdp_pot_t	$LSTAR1$	-5.537 [3.590]	-0.096 [0.375]	0.085 [0.267]	-0.125 [0.200]	9.232 [1.957]	0.105 [0.599]	0.036 [0.394]	0.348 [0.308]	0.3	p_5	1.020 [0.030]
	rd_gdp_t	$LSTAR1$	0.474 [0.161]	0.895 [0.064]	0.020 [0.034]	-0.020 [0.026]	-0.821 [0.177]	-	-	-	30.1	p_{89}	-0.285 [0.129]
x_t	gdp_pot_t	$LSTAR1$	0.574 [0.173]	-0.075 [0.060]	1.015 [0.039]	-0.040 [0.028]	-0.784 [0.124]	-	-	-	32	p_{76}	0.075 [0.129]
i_t	gdp_pot_t	$LSTAR1$	0.223 [0.241]	0.151 [0.063]	0.127 [0.047]	0.901 [0.044]	-	1.106 [0.298]	0.717 [0.186]	-0.866 [0.185]	3.1	p_{94}	0.611 [0.115]

Table A7.10 Final estimates of $STAR$ model when modelling state-dependency with respect to measures of financial development of the economy (standard errors in square brackets)

y_t	s_t	$G(s_t;\gamma,\boldsymbol{c})$	$\varphi_{\dots1}$	$\varphi_{\dots2}$	$\varphi_{\dots3}$	$\varphi_{\dots4}$	$\psi_{\dots1}$	$\psi_{\dots2}$	$\psi_{\dots3}$	$\psi_{\dots4}$	γ	$\boldsymbol{c}$	$\varphi_{\dots5}$
x_t	mzm_gdp_t	$ESTAR$	-2.551 [0.529]	-0.192 [0.061]	-0.102 [0.232]	0.500 [0.093]	3.514 [0.581]	-	1.116 [0.242]	-0.596 [0.099]	2.3	p_{90}	-0.083 [0.129]
	mf_gdp_t	$LSTAR1$	0.362 [0.136]	-0.013 [0.051]	1.031 [0.036]	-0.022 [0.023]	-	-0.395 [0.047]	-0.185 [0.070]	-	9.3	p_{77}	-0.070 [0.130]
i_t	mf_gdp_t	$LSTAR1$	0.091 [0.188]	0.159 [0.052]	0.126 [0.038]	0.970 [0.033]	-	-	-	-0.542 [0.092]	1.3	p_{95}	0.461 [0.118]

Table A7.11 Final estimates of $STAR$ model when modelling state-dependency with respect to variables related to Greenspan standard (standard errors in square brackets)

y_t	s_t	$G(s_t;\gamma,\boldsymbol{c})$	$\varphi_{\dots1}$	$\varphi_{\dots2}$	$\varphi_{\dots3}$	$\varphi_{\dots4}$	$\psi_{\dots1}$	$\psi_{\dots2}$	$\psi_{\dots3}$	$\psi_{\dots4}$	γ	$\boldsymbol{c}$	$\varphi_{\dots5}$
x_t	$sp500_t$	$ESTAR$	0.402 [0.120]	0.0769 [0.0596]	1.047 [0.036]	-0.0703 [0.0286]	-	-1.499 [0.346]	-0.400 [0.187]	0.453 [0.176]	0.2	p_{70}	-0.383 [0.122]
	$wilsh_t$	$LSTAR2$	0.091 [0.176]	0.02 [0.060]	1.0116 [0.036]	-0.007 [0.025]	1.212 [0.357]	-0.741 [0.141]	-0.178 [0.071]	-	32	p_{10} p_{91}	-0.082 [0.131]
	$djia_t$	$LSTAR2$	-0.018 [0.209]	0.048 [0.073]	0.951 [0.038]	-0.007 [0.029]	1.293 [0.416]	-0.802 [0.172]	-	-	2.6	p_9 p_{90}	0.023 [0.131]
i_t	$spcs_t$	$LSTAR1$	0.657 [0.524]	0.165 [0.063]	0.268 [0.069]	0.741 [0.098]	0.330 [0.079]	-	-	-	9.7	p_{29}	0.874 [0.089]
	wti_t	$LSTAR1$	-0.080 [0.606]	0.340 [0.088]	0.280 [0.078]	0.767 [0.111]	0.734 [0.314]	-0.305 [0.089]	-0.113 [0.065]	0.093 [0.059]	32	p_{13}	0.789 [0.144]

Appendix A.8

Table A8.1 Detailed results of estimation of equation (7.1) and p-values of subsequent tests for $CSGIRF_p^M(\pi)$

No.	z_t / s_t	α^-	α^+	β^-	β^+	H_0^1		H_0^{1a}		H_0^{1b}		H_0^2	
						F	χ^2	F	χ^2	F	χ^2	F	χ^2
1	x_{t-1}	-1.052 [0.000]	-1.051 [0.000]	-0.019 [0.000]	-0.018 [0.000]	0.532	0.530	0.307	0.304	0.796	0.796	0.000	0.000
2	x_{t-1}^{SM}	-1.155 [0.000]	-1.155 [0.000]	0.007 [0.000]	0.007 [0.000]	0.858	0.858	0.693	0.692	0.771	0.771	0.000	0.000
3	i_{t-1}^{SM}	-0.175 [0.000]	-0.179 [0.000]	0.338 [0.000]	0.119 [0.000]	0.000	0.000	0.395	0.393	0.000	0.000	0.000	0.000
4	x_{t-1}^{SV}	-1.112 [0.000]	-1.112 [0.000]	0.001 [0.000]	0.001 [0.000]	0.711	0.710	0.410	0.408	0.898	0.897	0.000	0.000

Table A8.2 Detailed results of estimation of equation (7.1) and p-values of subsequent tests for $CSGIRF_p^M(x)$

No.	z_t / s_t	α^-	α^+	β^-	β^+	H_0^1		H_0^{1a}		H_0^{1b}		H_0^2	
						F	χ^2	F	χ^2	F	χ^2	F	χ^2
1	x_{t-1}	-1.291 [0.000]	-1.282 [0.000]	-0.112 [0.000]	-0.108 [0.000]	0.552	0.550	0.301	0.298	0.898	0.897	0.000	0.000
2	x_{t-1}^{SM}	-1.787 [0.000]	-1.787 [0.000]	0.044 [0.000]	0.041 [0.000]	0.545	0.543	0.470	0.468	0.514	0.513	0.000	0.000
3	i_{t-1}^{SM}	-0.862 [0.000]	-0.862 [0.000]	-0.123 [0.000]	-0.030 [0.000]	0.000	0.000	0.850	0.849	0.000	0.000	0.000	0.000
4	x_{t-1}^{SV}	-0.585 [0.000]	-0.585 [0.000]	0.001 [0.000]	0.001 [0.000]	0.712	0.712	0.412	0.410	0.862	0.862	0.000	0.000

Table A8.3 Detailed results of estimation of equation (7.1) and p-values of subsequent tests for $CSGIRF_p^M(i)$

No.	z_t / s_t	α^-	α^+	β^-	β^+	H_0^1		H_0^{1a}		H_0^{1b}		H_0^2	
						F	χ^2	F	χ^2	F	χ^2	F	χ^2
1	x_{t-1}	2.386 [0.000]	2.392 [0.000]	-0.088 [0.000]	-0.084 [0.000]	0.552	0.550	0.311	0.308	0.847	0.847	0.000	0.000
2	x_{t-1}^{SM}	2.097 [0.000]	2.096 [0.000]	0.032 [0.000]	0.031 [0.000]	0.726	0.725	0.593	0.592	0.644	0.643	0.000	0.000
3	i_{t-1}^{SM}	5.275 [0.000]	5.278 [0.000]	0.212 [0.000]	0.090 [0.000]	0.000	0.000	0.593	0.592	0.000	0.000	0.000	0.000
4	x_{t-1}^{SV}	4.021 [0.000]	4.021 [0.000]	-0.004 [0.000]	-0.004 [0.000]	0.792	0.792	0.498	0.496	0.949	0.949	0.000	0.000

Table A8.4 Detailed results of estimation of equation (7.1) and p-values of subsequent tests for $Effectiveness(\pi)$

No.	z_t / s_t	α^-	α^+	β^-	β^+	H_0^1		H_0^{1a}		H_0^{1b}		H_0^2	
						F	χ^2	F	χ^2	F	χ^2	F	χ^2
1	x_{t-1}	-0.441 [0.000]	-0.439 [0.000]	-0.024 [0.000]	-0.023 [0.000]	0.565	0.563	0.312	0.309	0.890	0.890	0.000	0.000
2	x_{t-1}^{SM}	-0.551 [0.000]	-0.551 [0.000]	0.012 [0.000]	0.011 [0.000]	0.635	0.634	0.617	0.616	0.496	0.495	0.000	0.000
3	i_{t-1}^{SM}	-0.033 [0.000]	-0.034 [0.000]	0.068 [0.000]	0.023 [0.000]	0.000	0.000	0.306	0.304	0.000	0.000	0.000	0.000
4	x_{t-1}^{SV}	-0.277 [0.000]	-0.277 [0.000]	0.000 [0.000]	0.000 [0.000]	0.987	0.987	0.993	0.993	0.873	0.872	0.000	0.000

Table A8.5 Detailed results of estimation of equation (7.1) and p-values of subsequent tests for $Effectiveness(x)$

No.	z_t / s_t	α^-	α^+	β^-	β^+	H_0^1		H_0^{1a}		H_0^{1b}		H_0^2	
						F	χ^2	F	χ^2	F	χ^2	F	χ^2
1	x_{t-1}	-0.541 [0.000]	-0.536 [0.000]	-0.066 [0.000]	-0.064 [0.000]	0.566	0.564	0.305	0.303	0.933	0.933	0.000	0.000
2	x_{t-1}^{SM}	-0.852 [0.000]	-0.853 [0.000]	0.034 [0.000]	0.032 [0.000]	0.487	0.485	0.510	0.508	0.406	0.404	0.000	0.000
3	i_{t-1}^{SM}	-0.163 [0.000]	-0.163 [0.000]	-0.017 [0.000]	-0.003 [0.000]	0.000	0.000	0.272	0.269	0.000	0.000	0.000	0.000
4	x_{t-1}^{SV}	-0.146 [0.000]	-0.146 [0.000]	0.000 [0.000]	0.000 [0.002]	0.861	0.861	0.747	0.747	0.623	0.622	0.000	0.000

Table A8.6 Detailed results of estimation of equation (7.1) and p-values of subsequent tests for $Efficiency$

No.	z_t / s_t	α^-	α^+	β^-	β^+	H_0^1		H_0^{1a}		H_0^{1b}		H_0^2	
						F	χ^2	F	χ^2	F	χ^2	F	χ^2
1	x_{t-1}	0.816 [0.000]	0.820 [0.000]	-0.058 [0.000]	-0.055 [0.000]	0.522	0.520	0.293	0.291	0.820	0.820	0.000	0.000
2	x_{t-1}^{SM}	0.647 [0.000]	0.646 [0.000]	0.012 [0.000]	0.011 [0.000]	0.611	0.610	0.424	0.422	0.692	0.691	0.000	0.000
3	i_{t-1}^{SM}	0.198 [0.000]	0.208 [0.000]	-0.476 [0.000]	-0.144 [0.000]	0.000	0.000	0.093	0.089	0.000	0.000	0.000	0.000
4	x_{t-1}^{SV}	1.901 [0.000]	1.901 [0.000]	0.000 [0.000]	0.000 [0.000]	0.733	0.732	0.519	0.517	0.574	0.573	0.000	0.000

Table A8.7 Detailed results of estimation of equation (7.1) for $CSGIRF_p^{Sk}(\pi)$, $CSGIRF_p^{Sk}(x)$, and $CSGIRF_p^{Sk}(i)$

No.	z_t / s_t	$CSGIRF_p^{Sk}(\pi)$				$CSGIRF_p^{Sk}(x)$				$CSGIRF_p^{Sk}(i)$			
		α^-	α^+	β^-	β^+	α^-	α^+	β^-	β^+	α^-	α^+	β^-	β^+
1	x_{t-1}	1.578 [0.000]	-1.320 [0.000]	-0.920 [0.000]	-0.829 [0.025]	1.912 [0.000]	-1.189 [0.000]	0.034 [0.776]	-0.265 [0.132]	3.370 [0.000]	-1.132 [0.186]	3.048 [0.173]	-0.857 [0.791]
2	x_{t-1}^{SM}	3.361 [0.000]	-3.231 [0.000]	0.042 [0.000]	-0.069 [0.000]	3.835 [0.000]	-3.712 [0.000]	-0.003 [0.686]	-0.077 [0.000]	3.597 [0.000]	-3.464 [0.000]	0.031 [0.000]	-0.073 [0.000]
3	i_{t-1}^{SM}	-1.027 [0.000]	1.042 [0.000]	2.453 [0.000]	2.583 [0.000]	2.651 [0.000]	-2.578 [0.000]	-1.165 [0.000]	-1.980 [0.000]	-0.324 [0.000]	0.392 [0.000]	0.598 [0.000]	0.959 [0.000]
4	x_{t-1}^{SV}	-2.539 [0.000]	2.526 [0.000]	-0.079 [0.001]	0.093 [0.005]	-2.280 [0.000]	2.268 [0.000]	-0.075 [0.000]	0.091 [0.002]	2.373 [0.000]	-2.346 [0.000]	0.074 [0.000]	-0.080 [0.003]

Table A8.8 P-values of tests of sign and size asymmetries for $CSGIRF_p^{Sk}(\pi)$

No.	z_t / s_t	H_0^1		H_0^{1a}		H_0^{1b}		H_0^2		H_0^{2a}		H_0^{2b}	
		F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2
1	x_{t-1}	0.000	0.000	0.000	0.000	0.056	0.053	0.000	0.000	0.839	0.838	0.000	0.000
2	x_{t-1}^{SM}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.027	0.025
3	i_{t-1}^{SM}	0.000	0.000	0.000	0.000	0.511	0.510	0.000	0.000	0.173	0.170	0.000	0.000
4	x_{t-1}^{SV}	0.000	0.000	0.000	0.000	0.192	0.189	0.000	0.000	0.000	0.000	0.739	0.738

Table A8.9 P-values of tests of sign and size asymmetries for $CSGIRF_p^{Sk}(x)$

No.	z_t / s_t	H_0^1		H_0^{1a}		H_0^{1b}		H_0^2		H_0^{2a}		H_0^{2b}	
		F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2
1	x_{t-1}	0.000	0.000	0.000	0.000	0.000	0.000	0.307	0.303	0.161	0.157	0.278	0.276
2	x_{t-1}^{SM}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	i_{t-1}^{SM}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	x_{t-1}^{SV}	0.000	0.000	0.185	0.182	0.000	0.000	0.000	0.000	0.000	0.000	0.645	0.644

Table A8.10 P-values of tests of sign and size asymmetries for $CSGIRF_p^{Sk}(i)$

No.	z_t / s_t	H_0^1		H_0^{1a}		H_0^{1b}		H_0^2		H_0^{2a}		H_0^{2b}	
		F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2	F	χ^2
1	x_{t-1}	0.000	0.000	0.000	0.000	0.060	0.057	0.380	0.376	0.321	0.319	0.577	0.576
2	x_{t-1}^{SM}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001
3	i_{t-1}^{SM}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	x_{t-1}^{SV}	0.000	0.000	0.002	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.857	0.856

Appendix A.9

Figure A9.1 Relations between the six measures describing the monetary transmission and the selected model variables

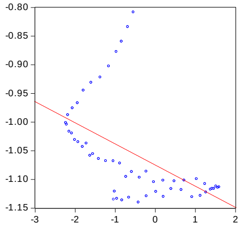
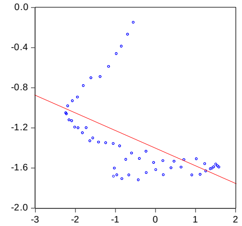
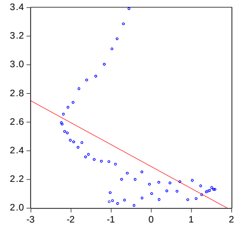
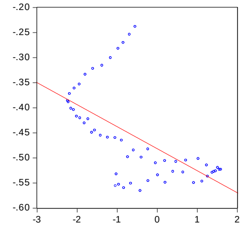
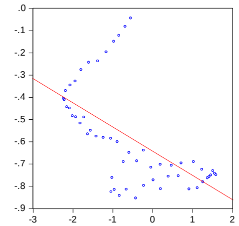
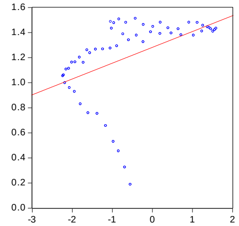
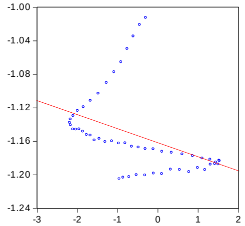
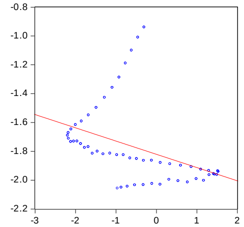
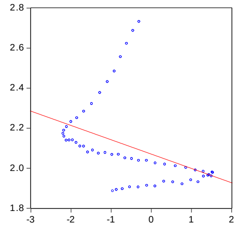
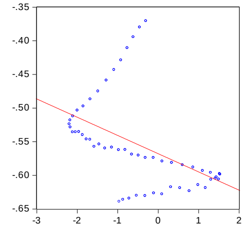
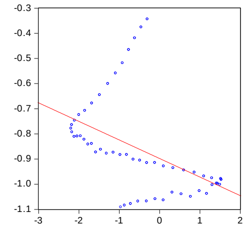
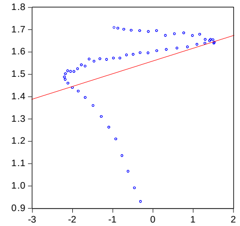
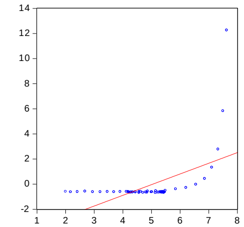
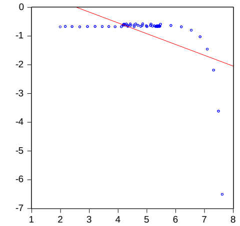
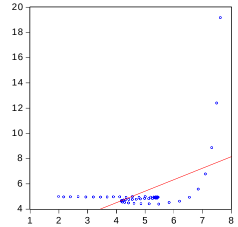
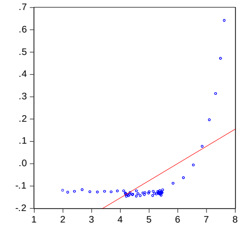
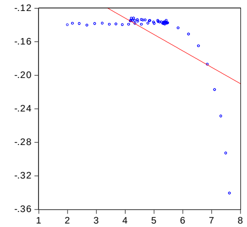
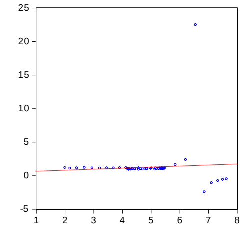
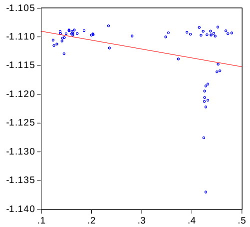
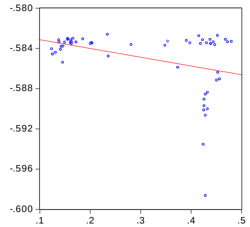
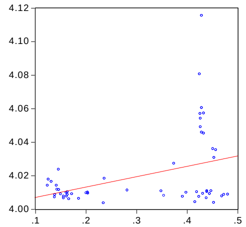
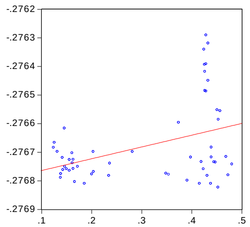
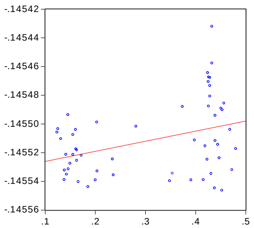
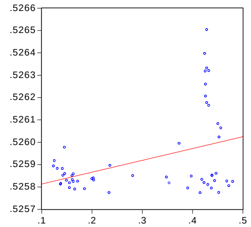
No.	z_t / s_t	$CSGIRF_t^M(\pi,\Omega_t)$	$CSGIRF_t^M(x,\Omega_t)$	$CSGIRF_t^M(i,\Omega_t)$	$Effectiv(\pi,\Omega_t)$	$Effectiv(x,\Omega_t)$	$Efficien(\Omega_t)$
1	x_{t-1}						
2	x_{t-1}^{SM}						
3	i_{t-1}^{SM}						
4	x_{t-1}^{SV}						

Figure A9.2 Relations between the six measures describing the monetary transmission and the selected measures of business cycle and climate

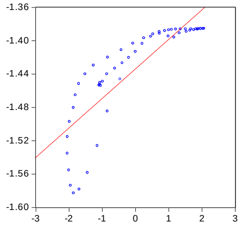
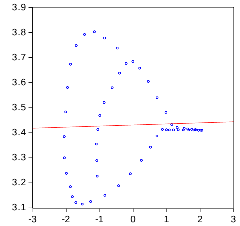
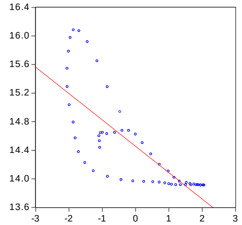
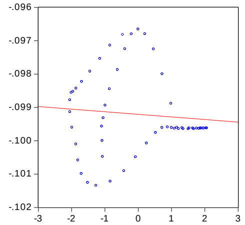
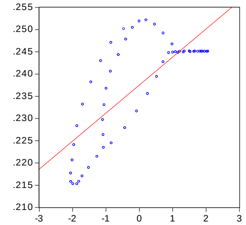
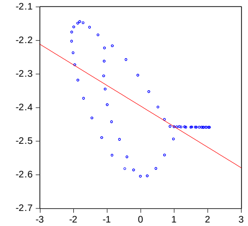
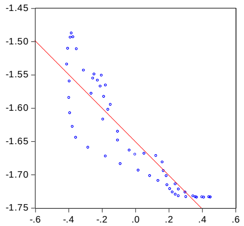
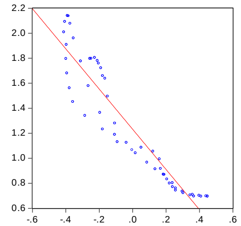
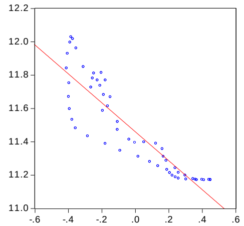
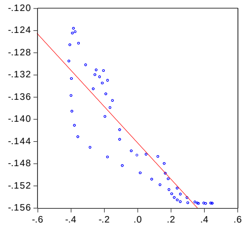
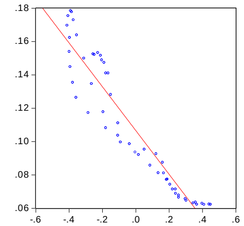
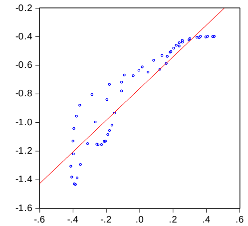
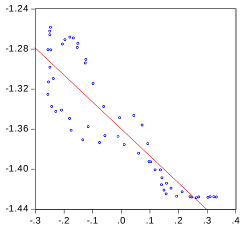
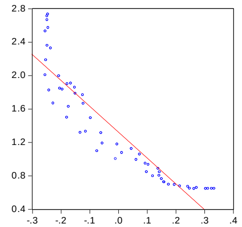
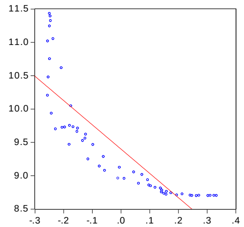
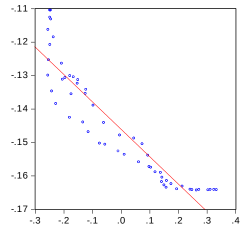
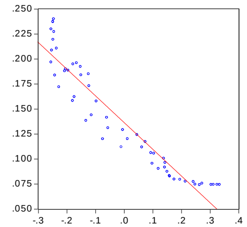
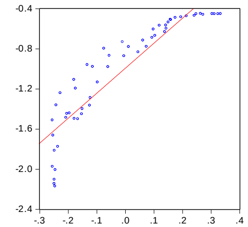
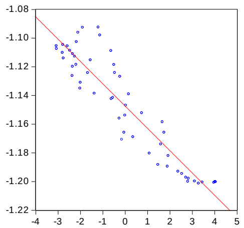
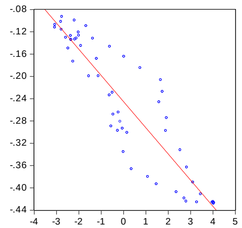
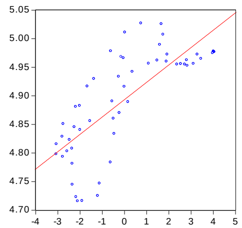
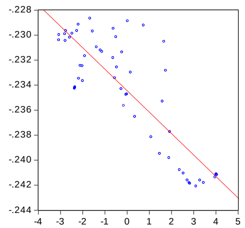
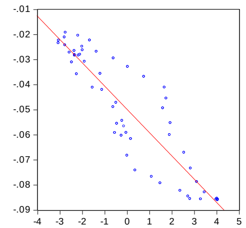
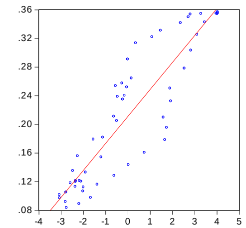
No.	s_t	$CSGIRF_t^M(\pi,\Omega_t)$	$CSGIRF_t^M(x,\Omega_t)$	$CSGIRF_t^M(i,\Omega_t)$	$Effectiv(\pi,\Omega_t)$	$Effectiv(x,\Omega_t)$	$Efficien(\Omega_t)$
1	cu_t						
2	ai_ma_t						
3	ai_di_t						
4	cs_t						

Figure A9.3 Relations between the six measures describing the monetary transmission and the selected measures of labour market conditions

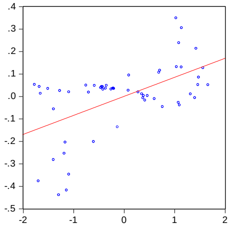
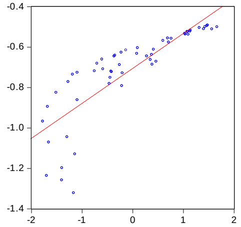
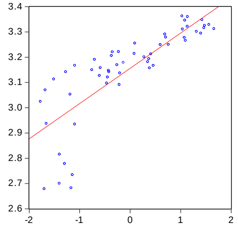
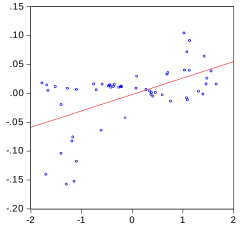
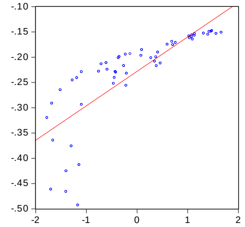
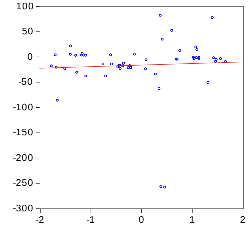
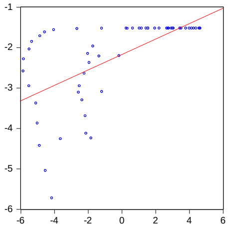
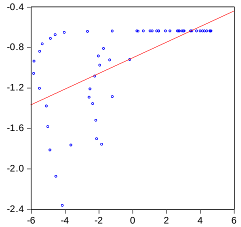
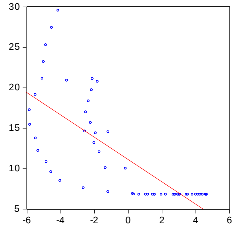
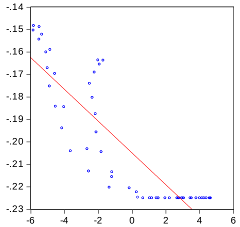
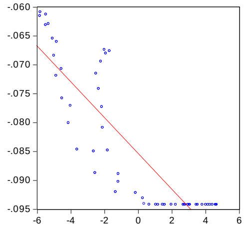
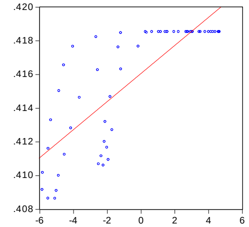
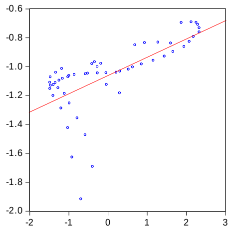
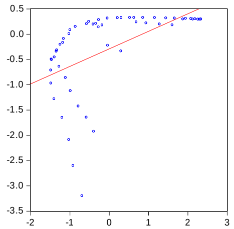
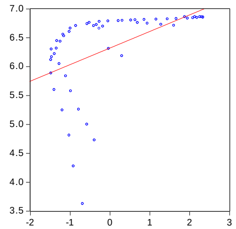
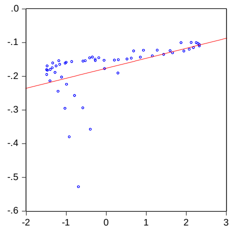
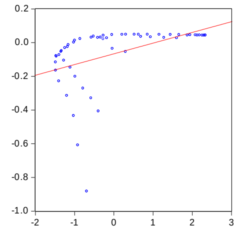
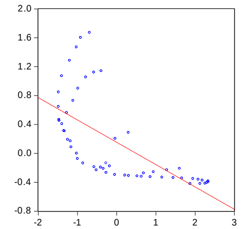
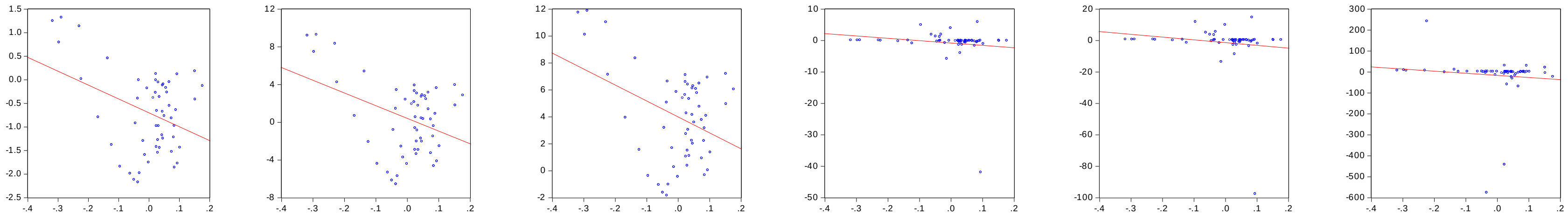
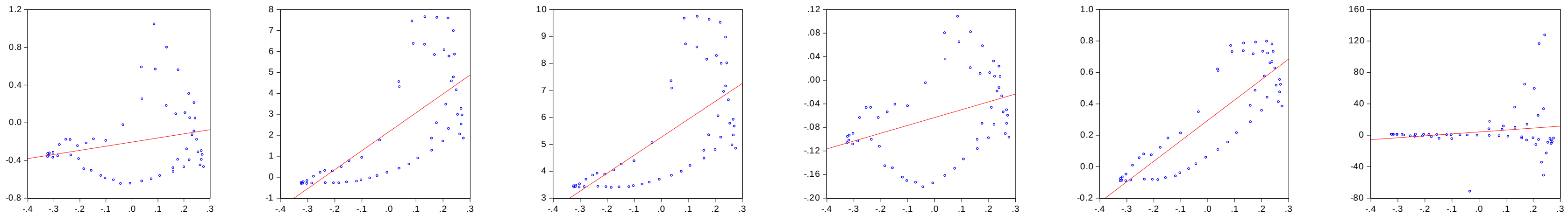
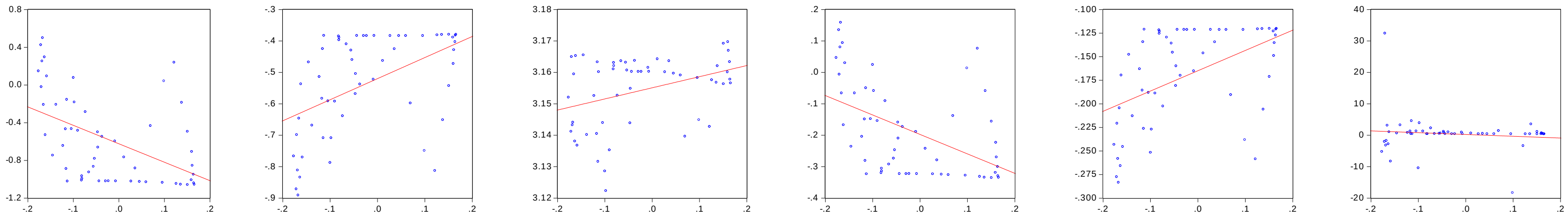
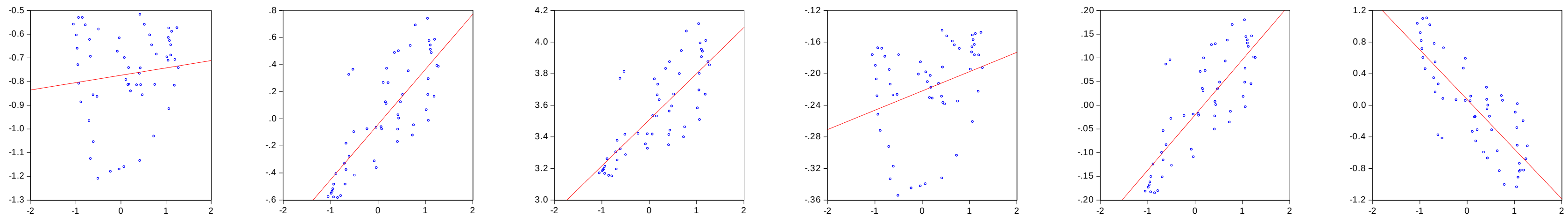
No.	s_t	$CSGIRF_t^M(\pi,\Omega_t)$	$CSGIRF_t^M(x,\Omega_t)$	$CSGIRF_t^M(i,\Omega_t)$	$Effectiv(\pi,\Omega_t)$	$Effectiv(x,\Omega_t)$	$Efficien(\Omega_t)$
1	$w\&s_t$						
2	$lmci_t$						

Figure A9.4 Relations between the six measures describing the monetary transmission and the selected measures of financial conditions

No.	s_t	$CSGIRF_t^M(\pi,\Omega_t)$	$CSGIRF_t^M(x,\Omega_t)$	$CSGIRF_t^M(i,\Omega_t)$	$Effectiv(\pi,\Omega_t)$	$Effectiv(x,\Omega_t)$	$Efficien(\Omega_t)$
1	$ccdi_t$						

2	$fcls_t$	
3	$fccs_t$	
4	$fcrs_t$	
5	mb_t	

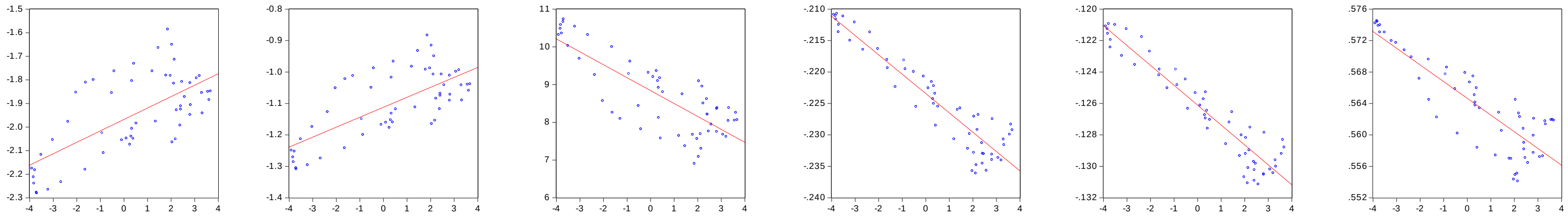
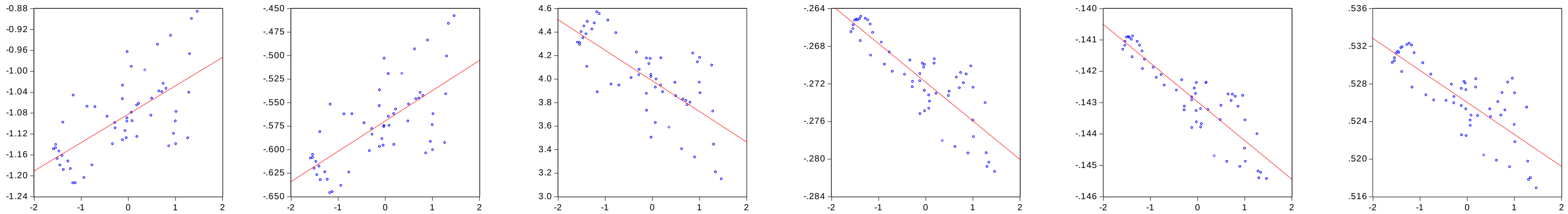
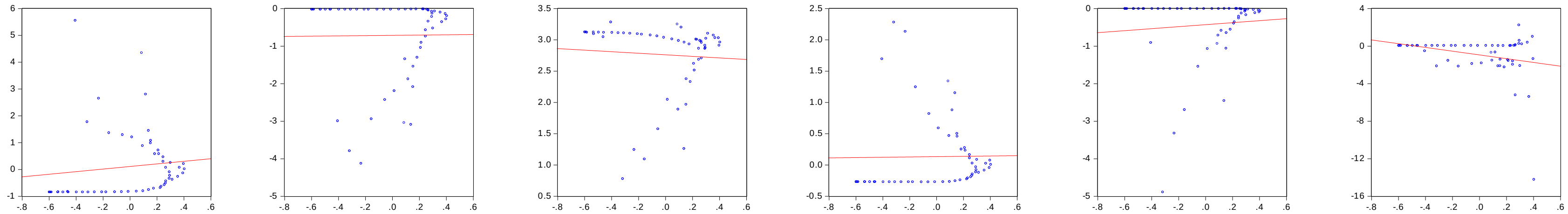
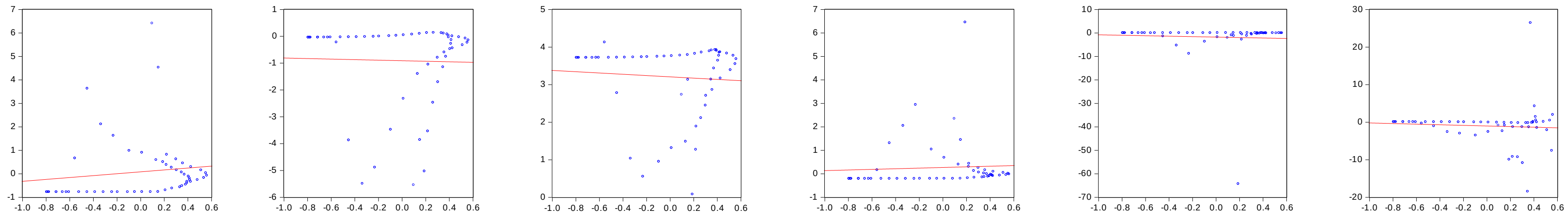
6	mzm_t	
7	$m2_t$	
8	nl_tl_t	
9	dr_t	

Figure A9.5 Relations between the six measures describing the monetary transmission and the selected measures of uncertainty

No.	s_t	$CSGIRF_t^M(\pi, \Omega_t)$	$CSGIRF_t^M(x, \Omega_t)$	$CSGIRF_t^M(i, \Omega_t)$	$Effectiv(\pi, \Omega_t)$	$Effectiv(x, \Omega_t)$	$Efficien(\Omega_t)$
1	$epui_t$						
2	$emeui_t$						

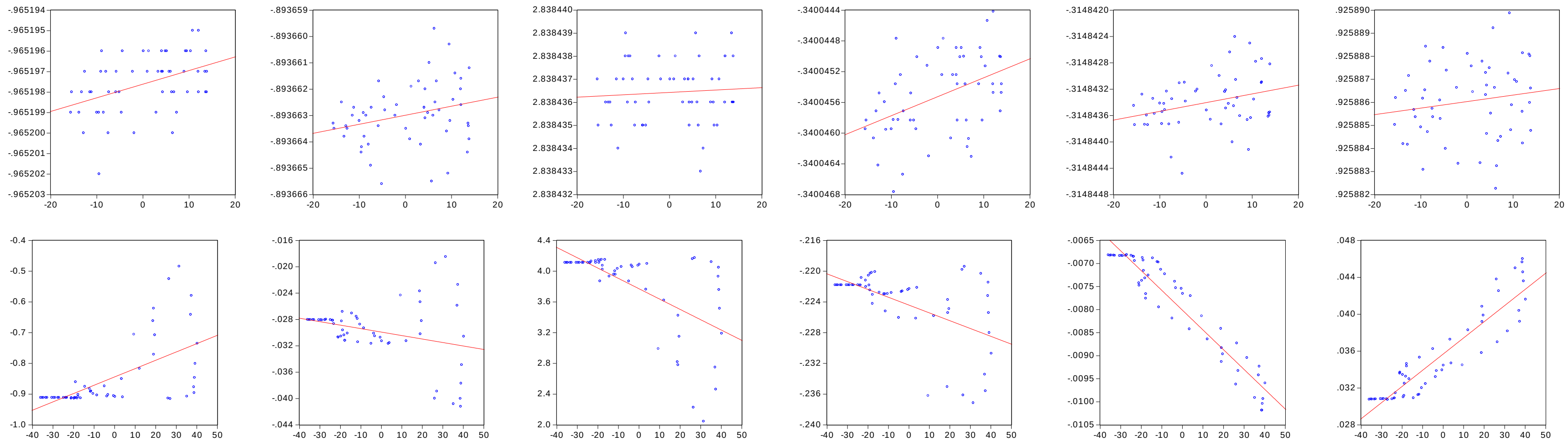
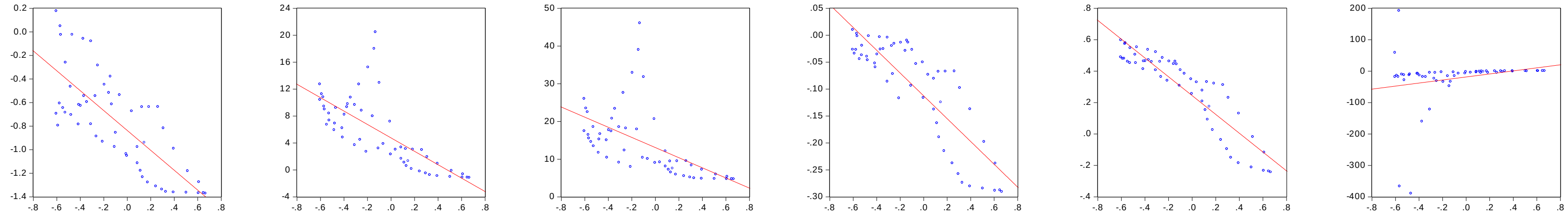


Figure A9.6 Relations between the six measures describing the monetary transmission and the selected measures of globalisation

No.	s_t	$CSGIRF_t^M(\pi, \Omega_t)$	$CSGIRF_t^M(x, \Omega_t)$	$CSGIRF_t^M(i, \Omega_t)$	$Effectiv(\pi, \Omega_t)$	$Effectiv(x, \Omega_t)$	$Efficien(\Omega_t)$
1	$wgdp_t$						



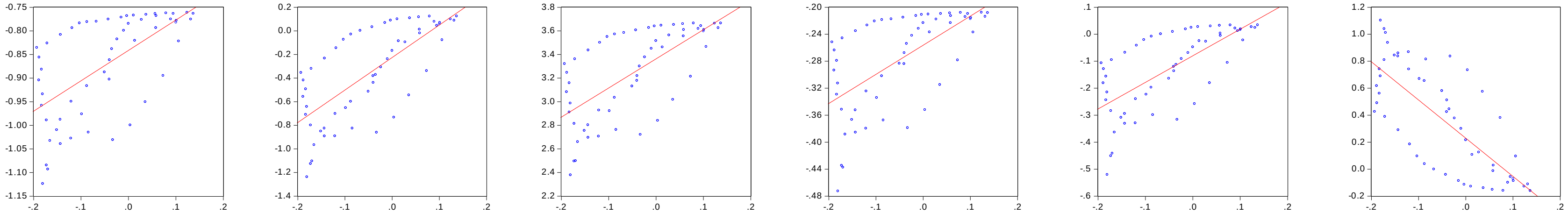
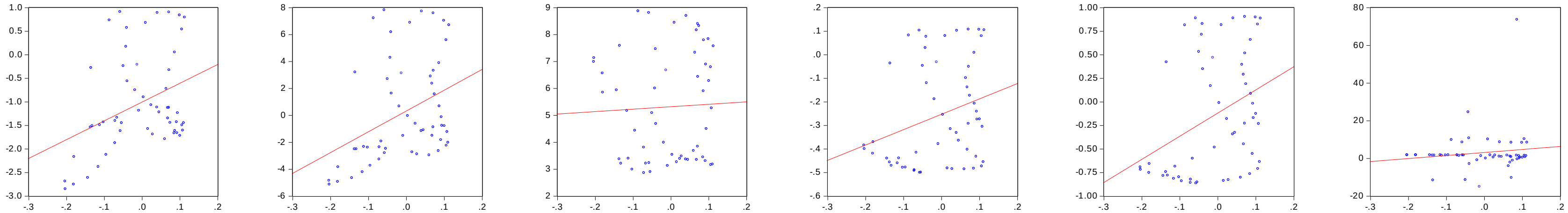
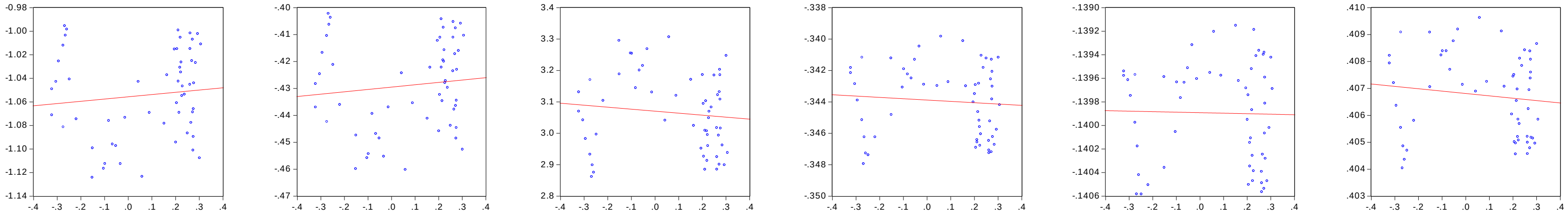
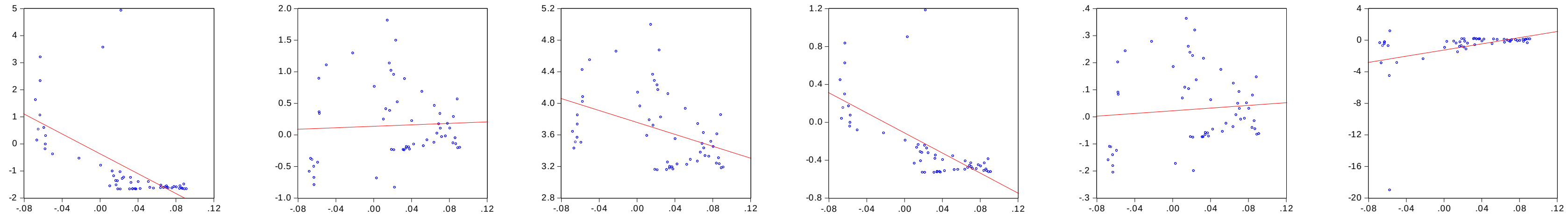
2	ws_gdp_t	
3	we_gdp_t	
4	e_gdp_t	
5	ca_gdp_t	

Figure A9.7 Relations between the six measures describing the monetary transmission and the selected measures of composition of the economy

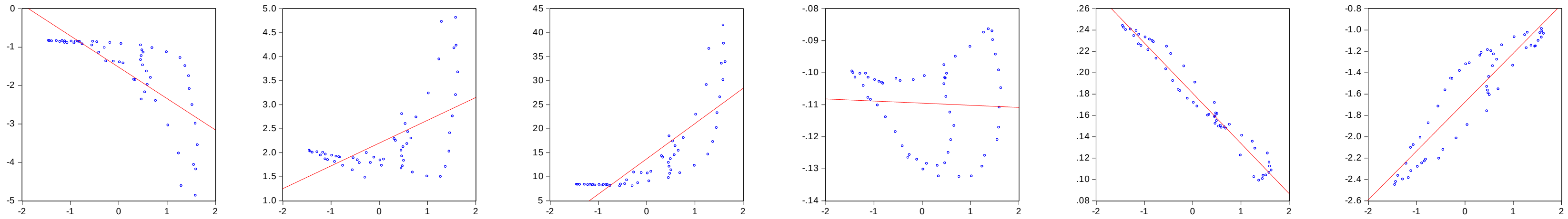
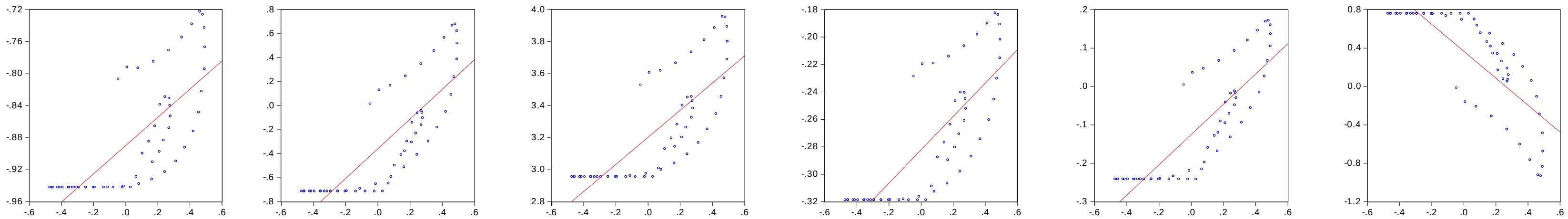
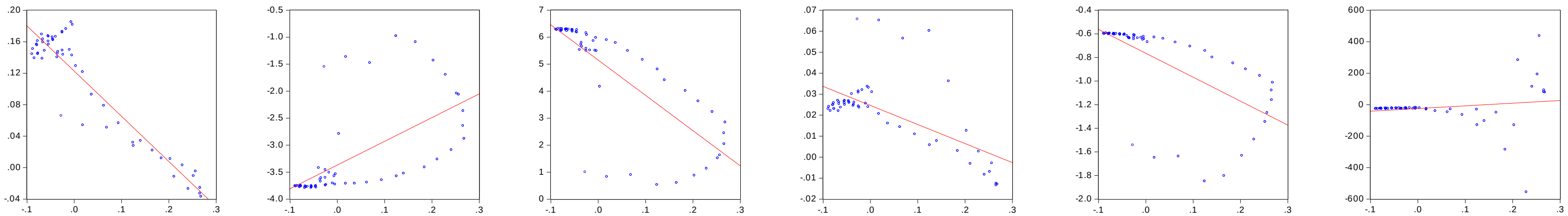
No.	s_t	$CSGIRF_t^M(\pi,\Omega_t)$	$CSGIRF_t^M(x,\Omega_t)$	$CSGIRF_t^M(i,\Omega_t)$	$Effectiv(\pi,\Omega_t)$	$Effectiv(x,\Omega_t)$	$Efficien(\Omega_t)$
1	$lshare_t$						
2	sva_gdp_t						

Figure A9.8 Relations between the six measures describing the monetary transmission and the selected measures of potential growth and development

No.	s_t	$CSGIRF_t^M(\pi,\Omega_t)$	$CSGIRF_t^M(x,\Omega_t)$	$CSGIRF_t^M(i,\Omega_t)$	$Effectiv(\pi,\Omega_t)$	$Effectiv(x,\Omega_t)$	$Efficien(\Omega_t)$
1	gdp_pot_t						

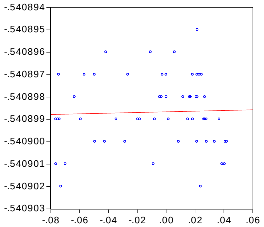
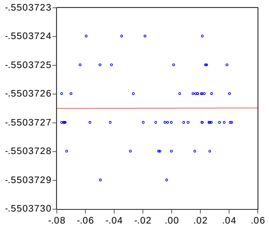
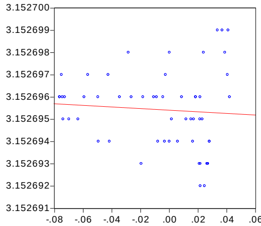
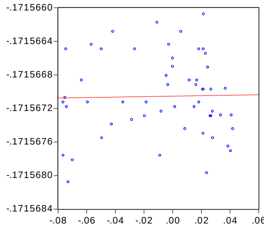
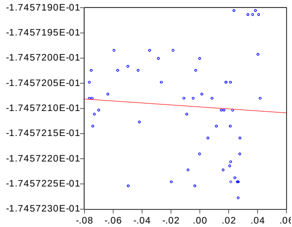
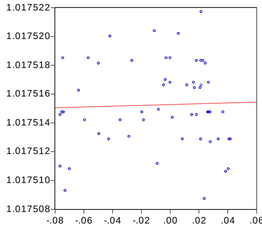
2	rd_gdp_t						

Figure A9.9 Relations between the six measures describing the monetary transmission and the selected measures of financial development of the economy

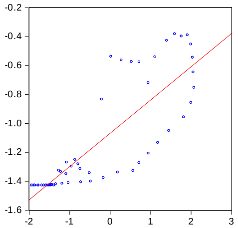
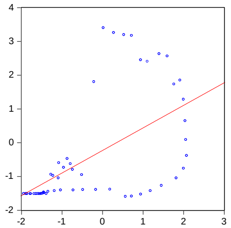
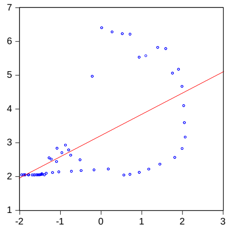
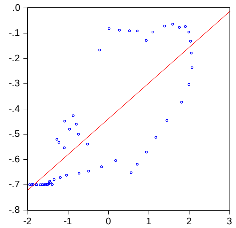
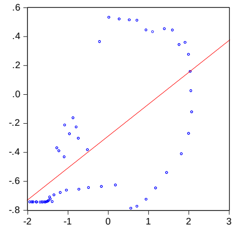
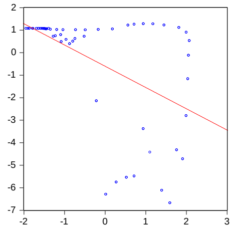
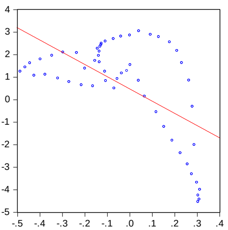
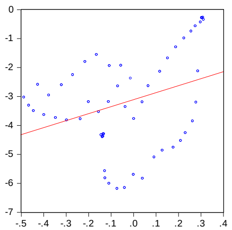
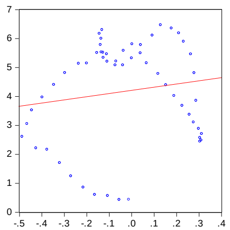
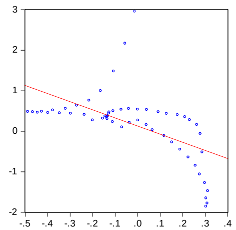
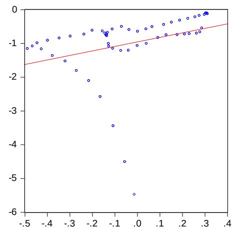
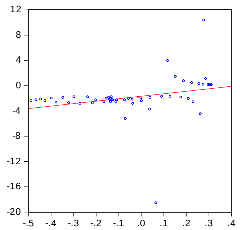
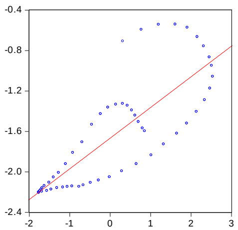
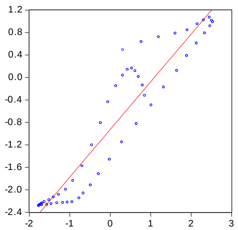
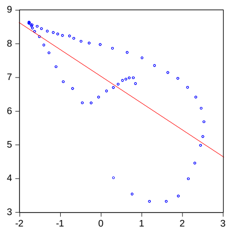
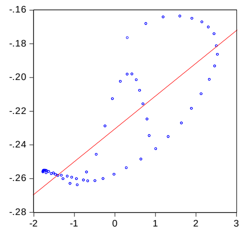
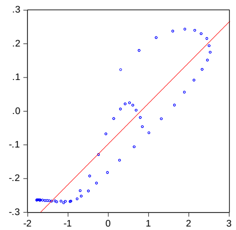
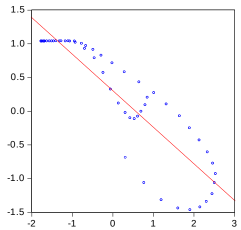
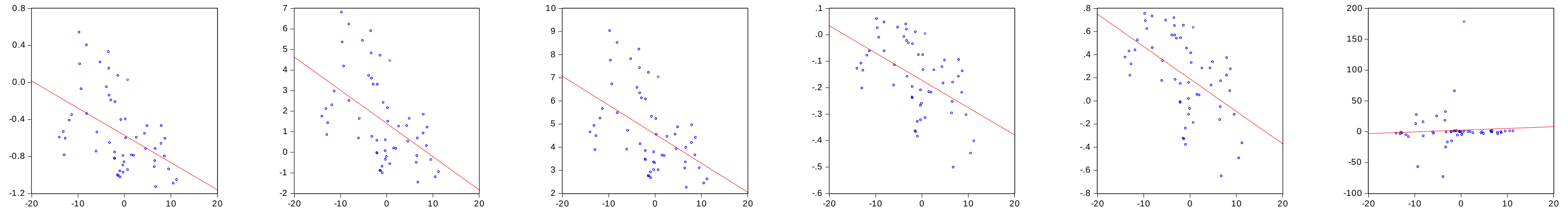
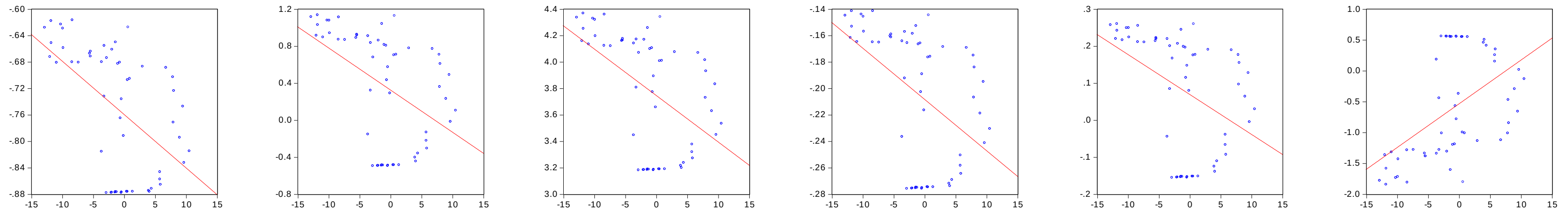
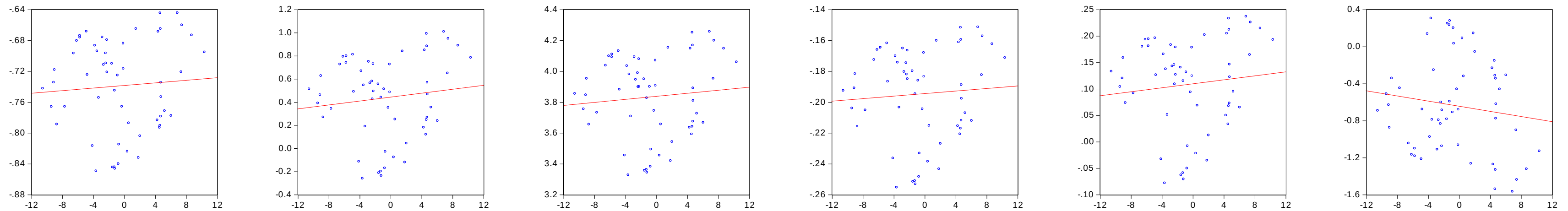
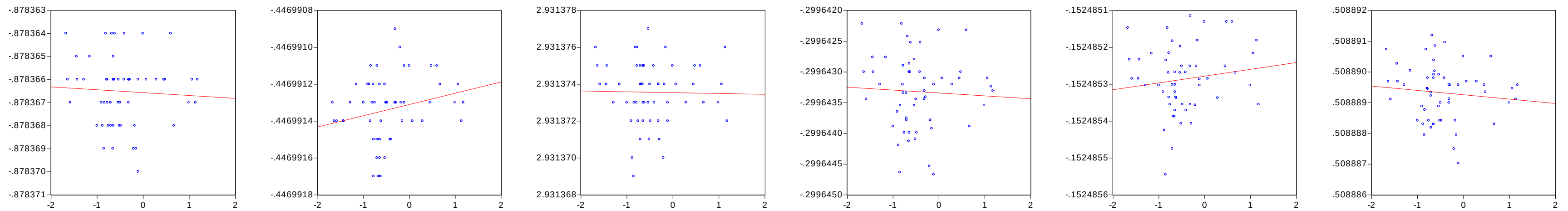
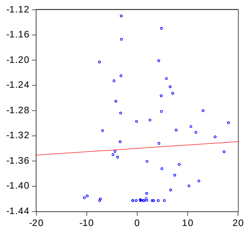
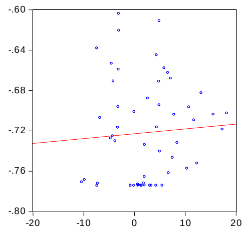
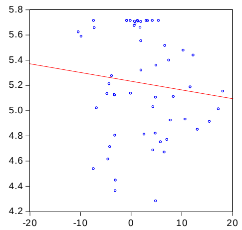
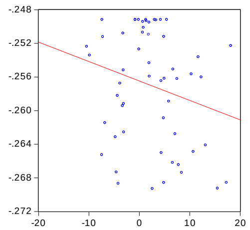
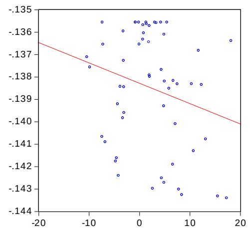
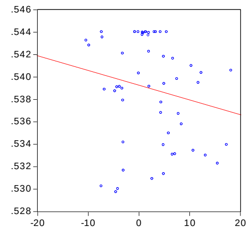
No.	s_t	$CSGIRF_t^M(\pi,\Omega_t)$	$CSGIRF_t^M(x,\Omega_t)$	$CSGIRF_t^M(i,\Omega_t)$	$Effectiv(\pi,\Omega_t)$	$Effectiv(x,\Omega_t)$	$Efficien(\Omega_t)$
1	mzm_gdp_t						
2	md_gdp_t						
3	mf_gdp_t						

Figure A9.10 Relations between the six measures describing the monetary transmission and the selected variables related to some aspects of Greenspan standard

No.	s_t	$CSGIRF_t^M(\pi,\Omega_t)$	$CSGIRF_t^M(x,\Omega_t)$	$CSGIRF_t^M(i,\Omega_t)$	$Effectiv(\pi,\Omega_t)$	$Effectiv(x,\Omega_t)$	$Efficien(\Omega_t)$
1	$sp500_t$						
2	$wilsh_t$						
3	$djia_t$						
4	$spcs_t$						

5	wti_t						

-1.12 -1.16 -1.20 -1.24 -1.28 -1.32 -1.36 -1.40 -1.44
-20 -10 0 10 20
-.60 -.64 -.68 -.72 -.76 -.80
-20 -10 0 10 20
5.8 5.6 5.4 5.2 5.0 4.8 4.6 4.4 4.2
-20 -10 0 10 20
-.248 -.252 -.256 -.260 -.264 -.268 -.272
-20 -10 0 10 20
-.135 -.136 -.137 -.138 -.139 -.140 -.141 -.142 -.143 -.144
-20 -10 0 10 20
.546 .544 .542 .540 .538 .536 .534 .532 .530 .528
-20 -10 0 10 20